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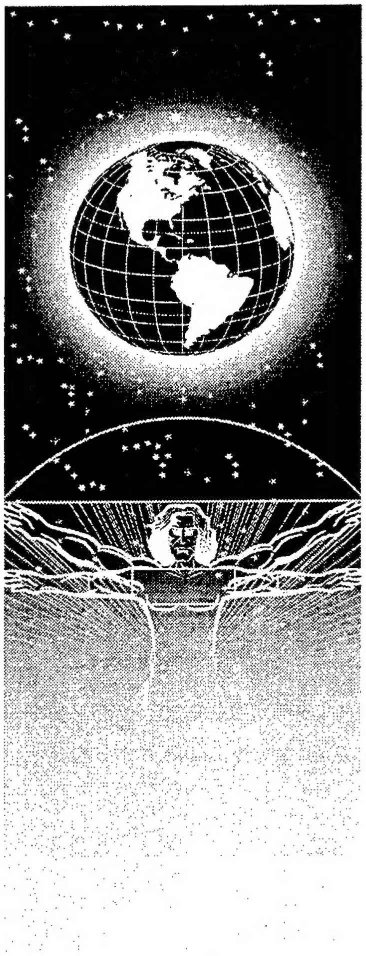

UNITED STATES AIR FORCE RESEARCH LABORATORY

Rapid Off-Load Manifold (ROLM) Concept Exploration

David A. Hablanian

Arthur D. Little, Inc.
Acorn Park
Cambridge, MA 02140

September 2000

Final Report for the Period September 1999 to September 2000

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Human Effectiveness Directorate
Deployment and Sustainment Division
Sustainment Logistics Branch
2698 G Street
Wright-Patterson AFB OH 45433-7604

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TECHNICAL REVIEW AND APPROVAL

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This report has been reviewed by the Office of Public Affairs (PA) and is releasable to the National Technical Information Service (NTIS). At NTIS, it will be available to the general public, including foreign nations.

This technical report has been reviewed and is approved for publication.

FOR THE COMMANDER

ALBERT S. TORIGIAN, Lt Col, USAF
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13. ABSTRACT *(Maximum 200 words)*
The objectives of the Rapid Off-Load Manifold (ROLM) concept exploration effort were to gather requirements and to develop and analyze concepts for a new fuels manifold cart to support Air Force Forward Area Refueling Points (FARP) operations. The requirements for the ROLM cart were developed based on discussions with the ROLM Integrated Product Team (IPT), observation of demonstration testing of the existing Forward Area Manifold (FAM) cart, and by submitting and compiling the results of a questionnaire to the end users. Concepts were developed and analyzed, leading to description in the form of Computer Aided Design (CAD) drawings and the fabrication of a scale model. The projected performance and features of the ROLM cart are compared to the existing FAM cart in this report.

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Preface

This report, prepared by staff members of Arthur D. Little, Inc., is the Final Report, CDRL A0002, for Delivery Order 0009 under contract F41624-96-D-5002/0009. he DO9 Program Monitor, Captain David Sanford.

The key technical personnel who participated in this effort and their areas of responsibility are as follows:

Michael Bryant
Nelson Carbonell
David Hablanian
Anne Lac
Paul McTaggart

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SRA T. Carbino
D. Carignan
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C. Dorney
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Capt. K. O'Connor
E. Sanchez
I. Skriblis
TSgt. E. Smith
D. Stark
C. Triggs

H. Batchelder (Consultant)
M. Jalbert (Consultant)

EXECUTIVE SUMMARY

Forward Area Refueling Points (FARP) were developed in the early 1980s after the failure of Operation Desert One to rescue American hostages being held in Iran. The Air Force began research to identify safer alternatives to using fuel bladders in the cargo bay of transport aircraft. FARP Operations are intended to provide fuel to any forward covert or overt battlefield area. It consists of using a Forward Area Manifold (FAM) Cart (Exhibit ES-1) to transfer fuel from a tanker aircraft to a maximum of three receiver aircraft via lightweight hose assemblies, in austere or remote locations.

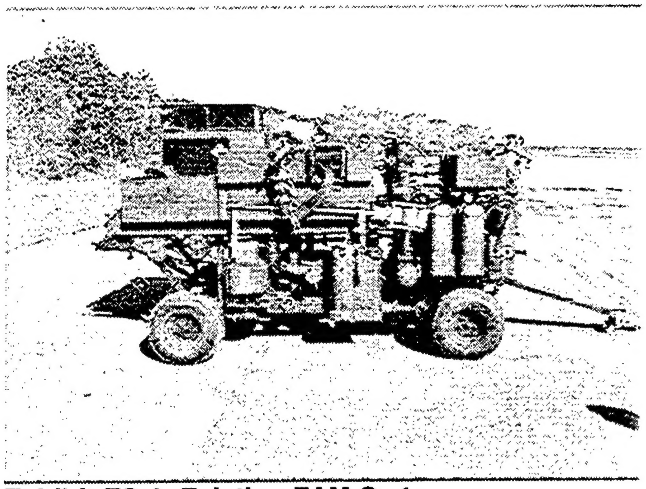


Exhibit ES-1: Existing FAM Cart

The primary tasks of this research effort were to:

- Gather and analyze cart requirements
- Develop conceptual level drawings
- Fabricate a scale model of a new fuels manifold cart
- Complete an engineering analysis of the existing and new design

The product of this effort includes objectives and requirements as determined by the Rapid Off-Load Manifold (ROLM) Integrated Product Team (IPT) and approved by the Air Force Research Laboratory (AFRL) contract monitor. The ROLM IPT includes representatives from the following groups:

- Arthur D. Little, Inc. (contractor)
- Deployment and Sustainment Division of the Human Effectiveness Directorate
- Fuels Division of the Propulsion Directorate
- Air Force Special Operations Command (AFSOC)
- Fuels Tech. Team
- Air Force Materiel Command Safety (AFMC/SE)
- Air Transportability Test Agency (ASC/EN)

This report includes the following information:

- Requirements Definition (Section 1)
- System Configuration (Section 2), including information on the following:
  - Theory of Operation (FAM Cart and ROLM Cart)
  - Hose
  - Hose Reels
  - Pump
  - Engine
  - Squeegee
- Analysis (Section 3), including information on the following:
  - Friction Losses and Pressure Drops
  - Life-Cycle Costs
  - Weight
  - Reliability
  - Set-up/Tear-Down Times
- Conclusions and Recommendations (Section 4)
- Requirements Table (Appendix A)
- FARP Fuel Cost Comparison (Appendix B)

The key accomplishments of this effort were as follows:

- Collected and prioritized requirements as defined by IPT
- Developed a detailed specifications table which incorporated input from all FAM Cart users
- Analyzed specifications and requirements to develop new cart concepts
- Developed a conceptual ROLM Cart design which responded to the requirements
- Created Computer Aided Design (CAD) drawings of new cart (Exhibit ES-2)
- Fabricated a 1/8th scale model of the conceptual design (Exhibits ES-3 and ES-4)
- Completed a detailed analysis of system frictional losses, pressure drops, life-cycle costs, cart weight, reliability, and set-up/tear-down times

The analysis indicates that maximum flow rates would be improved from 80 gpm to 300 gpm by selection of properly sized transfer hoses and resizing the pump/engine. This represents a 300% fuel flow rate increase. Currently, Headquarters Air Force Special Operations Command (HQ AFSOC), a component of United States Special Operations Command (USSOCOM), has issued a moratorium on three-point FARP operations due to the excessive time to refuel aircraft. ROLM technologies will allow the refueling of three aircraft simultaneously and correct a critical mission deficiency. Individual aircraft refueling times will be reduced 75%. New hoses have been selected which are continuous length to eliminate couplings and increase abrasion resistance. The defueling operation would use a battery-powered squeegee to minimize operator fatigue and reduce FARP disassembly times. Motorized hose reels would simplify the tear-down procedure. FARP tear-down times can be reduced from 35 minutes to 14 minutes, improving operational exfiltration times increasing personnel and equipment force protection. Life-cycle costs calculations indicate a 16% reduction in acquisition costs. Operation,

maintenance, deployment, and reliability analyses show that these features of the new ROLM Cart will be very similar to the existing FAM Cart. The ROLM Cart weight was estimated at 3,000 pounds which is similar to the existing FAM Cart.

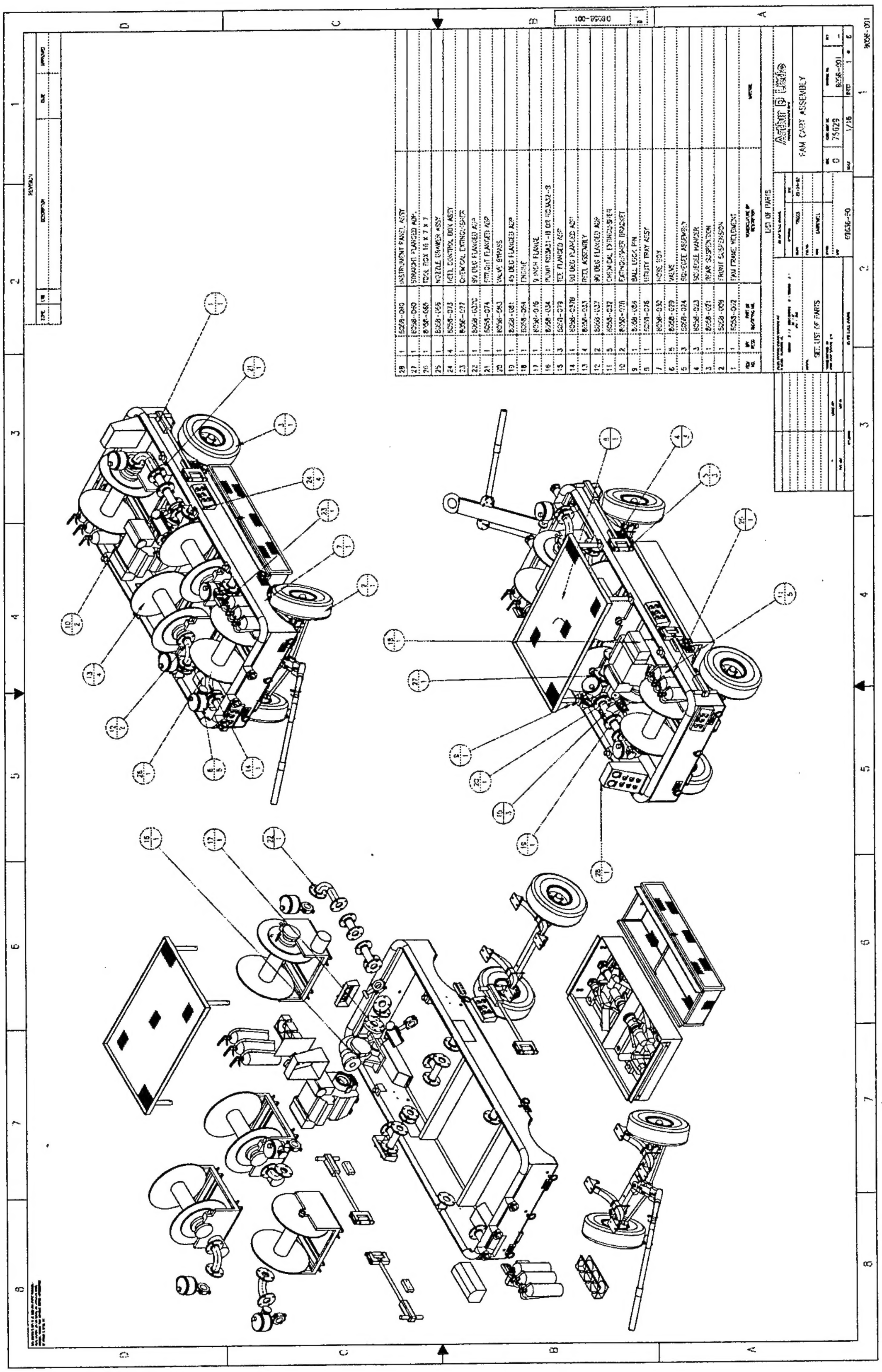


Exhibit ES-2: ROLM Cart Drawing

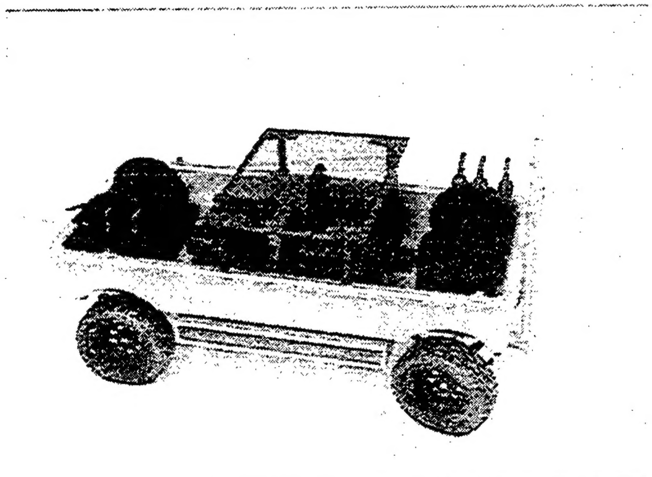


Exhibit ES-3: ROLM Cart Scale Model (Storage and Deployment Configuration)

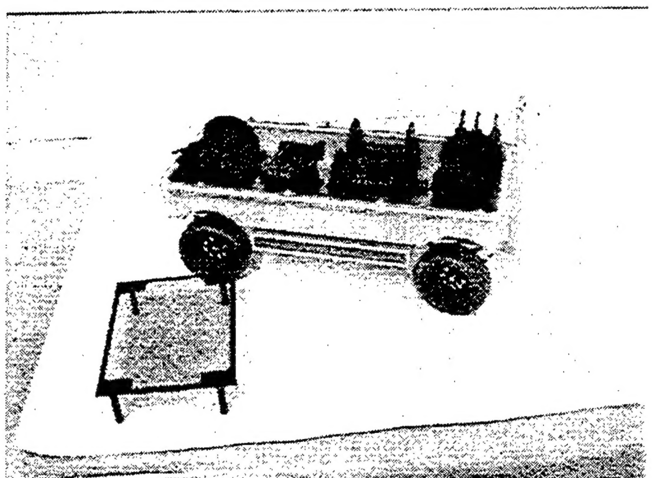


Exhibit ES-4: ROLM Cart Scale Model (Pumping Configuration with Overhead Basket Removed)

Table of Contents

List of Exhibits

1. REQUIREMENTS DEFINITION

A number of sources were utilized to compile the Rapid Off-Load Manifold (ROLM) system specification. The sources for the specification table included consultation with experts, Forward Area Manifold (FAM) cart reference literature, data collection during a Forward Area Refueling Point (FARP) demonstration, and a User Requirements Questionnaire. A combination of sources was used to ensure that user needs and expectations were accommodated and integrated into the final concept. The complete ROLM system specification table is included as Appendix A. This specification table shows the system improvements that were made as a result of requirements definition.

1.1 Expert Opinions

Experts participated in a series of teleconferences. These included representatives from the Air Force Research Laboratory (AFRL) at Wright-Patterson AFB, representatives from the Air Force Special Operations Command (AFSOC) at Hurlburt Field, FL, FAM cart team members at Hurlburt Field, FL, and Arthur D. Little, Inc. (ADL). During the initial teleconferences, guidance was provided to ADL on which components of the cart should be redesigned. Users discussed major problems and/or drawbacks encountered during FARP operations. From user comments, the User Requirements Questionnaire was generated to prioritize cart re-design issues.

1.2 FAM Cart Reference Literature

FAM cart reference literature include the following:

- Forward Area Refueling Point (FARP) Guide (1 May 1995)
- Computer Based Inspection (CBI) Lesson Guide 35028M1, Unit 22, Lesson 2 (23 May 1995)
- Operation, Maintenance, and Illustrated Parts Breakdown Forward Area Manifold Cart, T.O. 37A9-7-2-1 (1 August 1997)
- Fuel Systems, T.O. 1C-130B-2-5 (6 August 1997)
- Overhaul Fuel Booster Pump Assembly, T.O. 6J10-3-101-3 (30 September 1998)

This literature provided specification information for the existing FAM cart. The resulting specification table (included as Appendix A) is a side-by-side comparison of the existing FAM cart and the new ROLM design, highlighting the technological improvements that were made to the cart in accordance with the Statement of Work.

1.3 Data Collection during FARP Demonstration

During a three-point FARP demonstration at Hurlburt Field, FL, performance shortcomings of the FAM cart were confirmed. The overall breakdown time of 24 minutes (in daylight, with optimal weather conditions) was the most obvious area of concern. Users had previously indicated that this issue was imperative to improve. The complicated and lengthy breakdown procedures were also observed. Particular procedures contributing to a lengthy breakdown included hose defueling by a manually intensive squeegee process and restowing the hose into a tight S-shape configuration into baskets on top of the cart. Exhibits 1-1 and 1-2, taken during the demo, illustrate the difficulty of breaking down a three-point FARP.

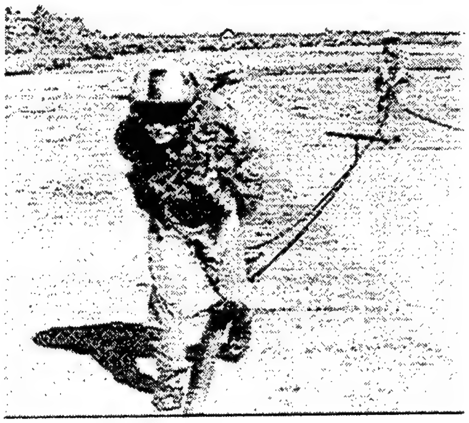


Exhibit 1-1: Manual Defueling with Squeegee

Exhibit 1-2: Unlocking Squeegee Pin Assembly

1.4 User Requirements Questionnaire

The User Requirements Questionnaire was distributed to FARP team personnel from each base that has a qualified FARP mission, including the following:

- AFSOC, Hurlburt Field
- Kadena AFB
- Dover AFB
- McGuire AFB
- Mildenhall AFB

The purpose of the User Requirements Questionnaire was to obtain feedback from end-users regarding what improvements were most important to make to the existing FAM cart. Based on the ratings of the users, a prioritized list of FAM cart attributes was developed.

The User Requirements Questionnaire consisted of 25 total attributes broken into three categories:

- Equipment/Performance (9)
- Operational Procedures (8)
- HSI/Human Factors attributes (8)

Desired attributes were identified from previous communications (teleconferences and meetings) with FAM cart users. Users were asked to rate these attributes on two scales. First, users were asked to rate each attribute on its level of acceptability with respect to the existing FAM cart. Second, users were asked to rate each attribute on its level of importance to the functionality of the FAM cart during a typical FARP operation. Both scales consisted of a seven-point rating scale where “1” was “completely unacceptable” or “not at all important” and “7” was “completely acceptable” or “extremely important.” Both Acceptability and Importance rating scales included an “N/A” choice for desired attributes that did not exist on the current cart.

A total of 17 questionnaires were completed. Based on subject ratings, the attributes were prioritized into the list shown as Exhibit 1-3.

Must Implement Changes – Low Acceptability (1-3.99), High Importance (5-7)		
Attribute	Average of Acceptability Ratings	Average of Importance Ratings
Stowing/Reconfiguring Hose	2.9	5.9
Defueling/Squeegee Process	3.2	5.9
No Fuel Gauge	3.4	5.3
Overall Breakdown Time	3.5	6.2
No Strength Labels on Tie-down Rings; No Label for maximum towing speed	3.5	5.3
Cart Not Maintainable Due to Lack to Technical Data	3.7	5.4
Hose Storage in Hose Reels	3.9	6.5
Should Implement Changes – Neutral Acceptability (4-4.99), High Importance (5-7)		
Attribute	Average of Acceptability Ratings	Average of Importance Ratings
Squeegee	4.1	6.0
No Labels on Fuel Control Valve	4.2	5.1
Hose Diameter	4.4	5.1
Offloading FAM Cart	4.7	6.3
Pump/Engine	4.7	6.2
Should Maintain or Improve – High Acceptability (5-7), High Importance (5-7)		
Attribute	Average of Acceptability Ratings	Average of Importance Ratings
Trident Hose Configuration	5.4	5.7
Manual Hand Brake	5.2	5.9
Moving Hose to Positions	5.3	5.3
Overall Set-up Time	5.8	6.0
Transportability	5.2	5.8
Would Be Nice to Improve But Not Required – Low to Neutral Acceptability (1-4.99), Low to Neutral Importance (1-4.99)		
Attribute	Average of Acceptability Ratings	Average of Importance Ratings
No Hard Ground Mounting Point for Shop Maintenance	3.7	3.9
Manual Engine Start	3.5	4.5
No Infra-red Readable Labels	3.5	4.9
Fuel Tank	4.8	4.8
Should Maintain – High Acceptability (5-7), Low to Neutral Importance (1-4.99)		
Attribute	Average of Acceptability Ratings	Average of Importance Ratings
Analog Controls	5.0	3.9
Refueling Point Distances	5.3	4.6
Positioning Cart, Fire Extinguishers, Water Can	5.1	4.9

Exhibit 1-3: Prioritized List of Attributes

The focus of the users was to address the attributes in order of their ratings. Cart attributes that ranked "low acceptability" and "high importance" (grouped as "Must implement changes") were examined first. Attributes that were grouped as "Should implement changes" were addressed second, etc.

1.5 ROLM System Specification Results

The final specification table (Appendix A) consists of a side-by-side comparison of FAM cart specifications and the new ROLM specifications. The specification table provides the essential product characteristics of ROLM and their associated metrics:

- *Equipment/Performance*: includes requirements for proper functionality and performance for intended purposes.

- *Induced environmental conditions*: includes requirements to minimize noise and withstand shock and vibration.
- *Natural environmental conditions*: includes requirements for proper operation and storage in all climates and environments.
- *Safety*: includes requirements for identifying and resolving system safety and health hazard issues.
- *Human Systems Integration/Human Factors*: includes requirements and considerations for providing an effective interface for the operator and maintainer and an easy-to-use system considering personal issues such as training.
- *Maintainability*: includes requirements and considerations for an easily maintained system.
- *Supportability*: includes requirements and considerations for resources needed for a supportable system in all operational scenarios.
- *Reliability and Availability*: includes requirements and considerations for the reliability and resulting availability of the system.
- *Deployability and Transportability*: includes considerations for the weight, footprint, and cube of the system, as well as requirements for providing a transportable system in all military environments.
- *Environmental compliance*: includes requirements for ozone-depleting substances, hazardous materials, emissions, and waste stream.
- *Survivability*: includes requirements for Nuclear/Biological/Chemical and battle damage survivability.
- *Documentation*: includes requirements for equipment markings and technical orders.
- *Interoperability:* includes requirements for comparability with all necessary aircraft and aircraft servicing ports.
- *Cost*: includes requirements for minimized life-cycle cost.

Wherever possible, specific information on product characteristics and performance was included. Where such information was not available, a recommended military specification was cited.

1.6 Key Performance Specifications

In the following paragraphs, the key performance specifications for the ROLM are identified and detailed. The figures are excerpted from the ROLM system specification table (Appendix A).

1.6.1 Overall Breakdown Requirements

Overall breakdown consists of a set of procedures which includes defueling, reconfiguring, and stowing hose. Users assigned these attributes 'low acceptability/high importance'. As a result, automatic hose reels and battery-powered squeegees were added to the design concept, both of which were selected to reduce breakdown time (Exhibit 1-4).

	FAM Cart	ROLM Cart	Comments
Equipment/Performance			
Drain Pump	External 28 VDC, 0.5 hp electric motor, 50 gpm pump, and 10' x 2" rigid suction hose	Uses primary pump on cart, Gorman Rupp centrifugal pump (#03H1-B), with squeegees	
Hose Storage	4 baskets	4 automatic hose reels (Nordic) with manual handcrank backup; spare hose in drawer under chassis	
Hose Evacuation	Drain pump (see above), squeegees	Drain pump (see above), battery powered squeegee	
Squeegees	Manually-pulled 2-roller assembly; rollers connected by pins; attached to 3' handle; fits 2" diameter hose	Battery-operated with tensioning rubber T-straps connecting 2 rollers (pinless for ease of use); fits 2" or 3" diameter hose; variable speed from 0-5 mph; telescoping handle from 2'-3'	Manual pull is possible in case of motor battery failure

Exhibit 1-4: Breakdown Requirements excerpted from System Specification

1.6.2 Flow Rate Requirements

System frictional loss (pressure drop) calculations combined with the FAM Cart pump curve determined that the FAM Cart was capable of a maximum output flow rate of 79 gpm. AFSOC personnel measured the maximum FAM Cart flow rate at 80 gpm (as seen in Exhibit 3-1). Users wanted a flow rate of 300 gpm for a three-point operation using the new ROLM. To meet this requirement, a different engine and pump were downselected, and hose diameter was increased (Exhibit 1-5).

	FAM Cart	ROLM Cart
Flow Rate	Maximum: 80 gpm (with a 3-point system, 27 gpm per point)	300 gpm (with a 3-point system, 100 gpm per point)
Pump/Engine	1-cylinder, air-cooled 6 hp JP-8 Lombardini engine connected to Gorman-Rupp centrifugal pump, rope starter backup	1-cylinder, air-cooled 13.3 hp JP-8 electric start Hatz engine, self-priming Gorman-Rupp centifugal pump, gear-reduced hand crank starter backup
Hose	Durodyne collapsible hose; black neoprene synthetic rubber cover; max. working pressure: 100 psi	Angus chemicoil lay-flat hose; polyurethane with integral abrasion-resistant sheath; max. working pressure: 300 psi
Hose Dimensions	2" diameter, max. continuous hose length: 100'; tanker-to-cart hose (1) x 200'; Cart-to-center-point hose (1) x 100'; Cart-to-side-point hoses (2) x 300'. All hoses greater than 100' require couplings for extension. Spare hose (1) x 100'.	3" diameter, max. continuous hose length: 660'; tanker-to-cart hose (1) x 200'; Cart-to-center-point hose (1) x 100'; Cart-to-side-point hoses (2) x 240'. Spare hose (1) x 240'.

Exhibit 1-5: Flow Rate Requirements excerpted from System Specification

1.6.3 Visual Feedback Requirements

Users commented on the lack of labels on the FAM cart, and asked that maximum tow speed and strength capacities of tiedown rings be labeled on the cart. Infrared readable gauges were also implemented to provide visual feedback to users during nighttime operations (Exhibit 1-6).

	FAM Cart	ROLM Cart	Comments
Human Systems Integration/Human Factors			
Displays and Interfaces	Daytime readable	Daytime and IR-readable	
Labeling	Daytime readable	Daytime readable	
Deployability and Transportability			
Tie-down Rings/Winches	Front/rear tie-down rings at 3,800 lbs; side rings at 1,900 lbs; two at front of cart, winching ring center aft of cart	Front/rear/side ring capacities all 5,000 lbs; max. strength ring capacities will be labeled, cart basket also with tie-down rings	
Ground Transportability	Unknown	Max. tow speed: 20 mph (will be labelled)	
Documentation			
Equipment Markings	Unknown	15	
Equipment/Performance			
Gauges	Pressure/vacuum gauge on pump inlet and manifold	Pressure/vacuum gauge on pump inlet and manifold; JP-8 engine fuel-level gauge	ROLM pressure gauges will be illuminated and IR-readable

Exhibit 1-6: Visual Feedback Requirements excerpted from System Specification

2. SYSTEM CONFIGURATION

This section discusses the theory of operation and the proposed system configuration of the ROLM Cart.

2.1 Theory of Operation

The theory of operation is first presented for the existing FAM Cart, followed by the new ROLM Cart.

2.1.1 FAM Cart

The existing FAM Cart is designed primarily as a manifold that maintains pressure and flow rates to receiver aircraft. The tanker and receiver aircraft typically leave their engines running throughout the operation. Under normal conditions, the pump and engine of the FAM Cart are utilized in operations. However, in the event of pump or engine failure, or with use of open port nozzles, the cart may be utilized simply as a manifold.

The FAM Cart is equipped with a manually started (rope-pulled), one-cylinder air-cooled 9.2 horsepower (HP) diesel engine manufactured by Lombardini. The engine is directly connected to a Gorman-Rupp self-priming centrifugal pump. The system has no electrical system or battery. A series of five control levers are used to select the valve positions allowing refuel or defuel (hose evacuation) modes of operation.

Fuel is transferred from the tanker aircraft through the tanker mounted single point refueling (SPR) panel to the FAM Cart using aircraft fuel dump pumps onboard the tanker aircraft. The dump pumps of the tankers main tanks, auxiliary tanks, and forward and aft external tanks are identical. The dump pumps are submerged centrifugal pumps manufactured by Hydro-Aire (Model #60-371). Exhibit 2-1 (taken from Technical Order #1C-130B-2-5) summarizes the fuel transfer rates for various combinations of tanker storage tanks.

Dump Pumps Operating	Rate (lbs. / min.)	Rate (gal. / min. of JP-8)
Main Tanks (4)	2,000	298
Main and Aux. Tanks (6)	2,770	413
Main and Ext. (if installed) Tanks (6)	2,700	403
Main and Ext. (if installed) Tanks (8)	2,950	440
Main, Aux., and Ext. (if installed) Tanks (8)	3,690	550
Main, Aux., and Ext. (if installed) Tanks (10)	3,900	582

Exhibit 2-1: MC-130 Fuel Dumping Rates

Fuel is received at the FAM Cart from the tanker through 200 feet of 2-inch collapsible fuel hose. Fuel then flows through an emergency shut-off valve to the centrifugal pump. Fuel flows through the pump to the fuel/defuel (FDF) directional valve. When this valve is in the fuel position, fuel passes through the valve and manifold out to a maximum of three refueling points. Each point can be opened or closed independently of each other, so that one or all may be used for refueling. Each refueling point uses 2-inch collapsible fuel hose of either 100-foot or 300-

foot length. Total hose length for all four lines is 900 feet with an additional 10-foot section of non-collapsible hose for defueling operations.

The FAM Cart is equipped with two gauges, intake pressure and manifold pressure, that provide pressure and vacuum readings for both refuel and defuel modes of operation. The manifold gauge indicates the pressure at the discharge manifold and the intake pressure gauge indicates vacuum/pressure from the 200-foot tanker supply hose. In defuel (hose evacuation) mode the discharge manifold gauge shows a vacuum because fuel is being evacuated from the discharge hose and manifold.

Once the refueling operation is complete, all hoses are defueled by positioning the FDF directional valve to the defuel setting, followed by manually pulling a squeegee over all lengths of hose. A defuel pump located on a 10-foot section of non-collapsible hose (located at the SPR panel) assists the FAM Cart-mounted centrifugal pump in the defueling operation. Once defueling is complete all hoses are folded into baskets on the FAM Cart and the cart is then pushed back onboard the tanker aircraft.

2.1.2 ROLM Cart

The theory of operation for the new ROLM Cart is very similar to the existing FAM Cart with the following exceptions. All fuel hoses will be 3-inch diameter and will be continuous length (no in-line fittings). The hoses will be stored on electrified motor-driven hose reels. The cart will contain a self-priming centrifugal pump. The engine will have electric start and all valves will be electrically controlled. A squeegee is still required for defueling operations but will be battery powered so that the operator will only be required to walk the length of the hose while holding the squeegee handle. This approach will eliminate the small defuel pump currently used while maintaining system simplicity and reliability.

Details of all major ROLM cart components are discussed below.

2.2 Chassis

The new ROLM chassis (Exhibit 2-2) incorporates unique features to simplify the design and provide weight reduction while providing maximum transportability. It has a maximum tow speed of 20 mph and is capable of being air transported and deployed in a matter of minutes. A summary of the various design features and components of the chassis is provided below.

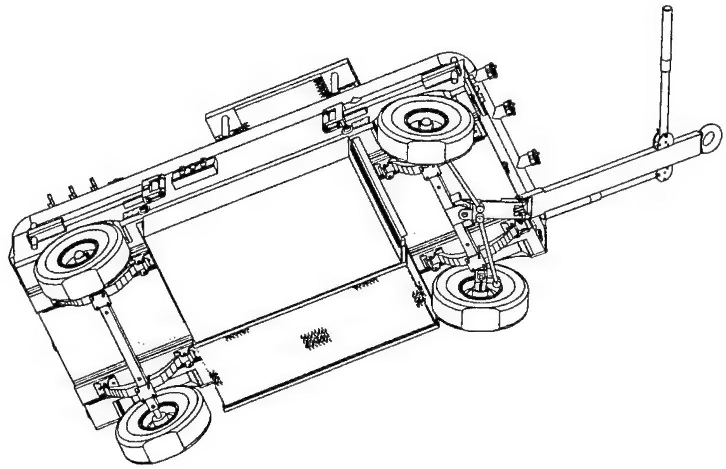


Exhibit 2-2: Bottom View of ROLM Chassis

2.2.1 Frame The frame will be constructed from a structural aluminum unibody to reduce weight and minimize corrosion-related maintenance. Structural members will be made of aluminum 6061-T6. Non- structural elements will be made of 5052 aluminum alloy. Forklift tubes will be incorporated into the prototype to add structural support to the frame and to aid in cart movement should a forklift be available.

2.2.2 Manifold The chassis will have a peripheral fuel manifold bolted to the frame which provides structural rigidity and simplifies the fuel piping distribution. The manifold will be constructed of structural aluminum tubing and is bolted to the chassis. The manifold will have two drain plugs located at low points to provide draining of fuel for maintenance activities.

2.2.3 Suspension The chassis suspension will consist of four elliptical leaf springs connected to the undercarriage using kingpins and shackles. The axle will be rigidly mounted to the spring's back rail using 'U' bolts. An Ackermann linkage will provide steering and stability while being towed at speeds up to 20 mph. The tires will be pneumatic bias ply (under 100 psi for deployability requirements). The cart turning radius will be 18.5 feet which is comparable to that of a small car.

2.2.4 Tow Bar An aluminum tow bar with a lunette eye will be provided for towing. The tow bar will also have two foldable bars for pushing/maneuvering the cart. The foldable bars allow personnel to push the cart from a position that is outboard of the chassis wheelbase. This safety feature ensures that fallen personnel will not be run-over by the cart. The tow bar will also have two detents. The first detent locks the bar in a vertical position for transportation. The second detent locks the bar angled to the ground but at an ergonomic height for the folding bars to be used for maneuvering. When the bar is near the horizontal plane, it can be used for towing.

2.2.5 Storage A drawer will be provided under the frame and between the axles for storing the nozzles and other miscellaneous items while a fixed basket with a flip-down front will hold the

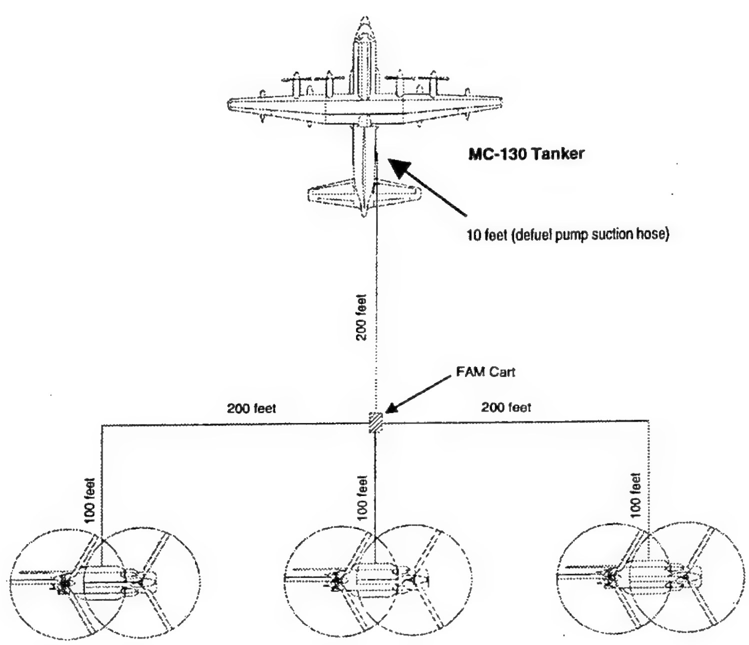
spare 240' hose. The drawer and basket do not interfere with the forklift tubes or with the required ramp clearances.

2.3 Hose

The hose used with the current FAM Cart is a 2-inch collapsible hose made by Durodyne, Inc. The primary deficiencies with this hose are poor abrasion resistance (in some instances hoses wear through after one mission and must be replaced), significant weight for it's size (0.59 pounds per foot without fittings), and a maximum continuous length of 100 feet (a 240-foot continuous length hose would eliminate the weight, cost, and leakage associated with fittings).

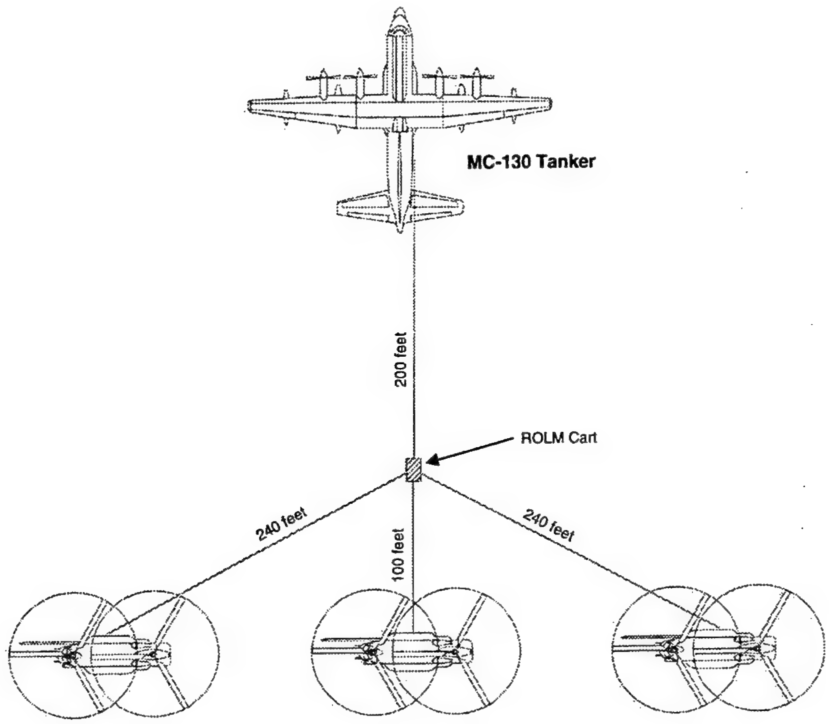
The search for a new hose led to discussions with 17 hose manufacturers worldwide. US manufacturers typically fabricate hose by laying the raw material onto a steel mandrel. This approach typically limits the continuous hose length to a maximum of 100 feet (although there are exceptions). European and Asian manufacturers typically extrude the hose which allows for a theoretical unlimited length, although typical continuous lengths are between 400 and 700 feet (based on 3-inch diameter) for handling purposes.

Hose is manufactured in three styles: rigid, collapsible, and lay-flat. The total hose length for the FAM Cart is 910 feet (Exhibit 2-3) while the ROLM Cart requires 780 feet (Exhibit 2-4) due to the change in hose geometry. The overall length of the hose makes the use of rigid hose impractical due to the enormous physical volume it would consume.



Note: Diagram not to scale

Exhibit 2-3: FAM Cart Hose Configuration and Length



Note: Diagram not to scale

Exhibit 2-4: ROLM Cart Hose Configuration and Length

Collapsible hose has an oval cross section with no pressure applied and is easily compressed with minimal force to resemble a lay-flat hose. Lay-flat hose consumes a very minimal height (typically ~1/2 inch for a 3-inch diameter hose). Nine manufacturers were identified as potential suppliers of collapsible or lay-flat hose. Of these, five manufacturers were able to supply a hose compatible with JP-8 fuel. Exhibit 2-5 provides data supplied by the five fuel hose manufacturers. Of these five manufacturers, two (N.P.R. Jones and I.V.G. Hose) have hose weights that are clearly beyond the weight limitations of the ROLM Cart application. One (Snap-Tite) stated that the performance of their hose would be very similar to the Angus Chemicoil product but would weigh an additional 23 pounds per 100 feet of hose.

Manufacturer	Durodyne*	Durodyne	Angus	Angus	Snap-Tite	N.P.R. Jones	I.V.G. Hose
Model #	AE320-32	New	Chemicoil	Offshore 850	Unknown	Unknown	Unknown
Lay-flat or Collapsable	Collapse	Collapse	Lay-flat	Lay-flat	Lay-flat	Collapse	Lay-flat
Maximum Length (ft)	100	250	660	660	660	500	400
Hose Color	Black	Black	Green	Green	Blu, Br, Yel, Grn	Unknown	Unknown
Method of Construction	Mandrel	Extruded	Extruded	Extruded	Extruded	Mandrel	Extruded
Maximum Working Pressure (psi)	100	100	300	425	300	300	200
Average Burst Pressure (psi)	300	300	600	850	600	600	800
Hose Cover Material	Neoprene	Neoprene	Polyurethane	Polyurethane	Polyurethane	Buna	Polyurethane
Gardner Abrasion Test (Cycles)	1130	3940	2640	2210	Not Tested	Not Tested	Not Tested
Working Temp Range (°F)	-40 to +160	-40 to +160	-58 to +158	-58 to +158	-55 to +210	-40 to +160	-58 to +160
Minimum Conductivity=1 Ohm/ft	Copper	Copper	Copper	Copper	Stainless	Stainless	Copper
3" Bare Hose Cost per Foot	$27.30*	$7.90	$6.50	$11.10	$7.13	$15.63	$9.50
Wall Thickness (inches)	0.130*	0.160	0.087	0.125	0.120	0.315	0.355
Hose Weight per 3" x 100'	59*	90	37	62	60	177	151

* Data is for the currently used Durodyne 2" hose (not a 3" hose)

Exhibit 2-5: Hose Comparison

Samples of the new Durodyne hose, the Angus Chemicoil hose, and the Angus Offshore 850 hose were obtained for evaluation purposes. A Gardner Abrasion Resistance Test was performed per ASTM D2486 on each hose sample.

The Gardner abrasion test was originally designed for measuring the scrub resistance of interior latex paint. Due to the limited number of abrasion test devices and procedures, the Gardner equipment (see Exhibit 2-6) is continuously modified and used for abrading other types of surfaces. For this program, a custom test fixture was made from aluminum "T" stock. The fixture held the hose section on edge while sliding back and forth on an abrasive surface (see Exhibit 2-7). The Gardner device counts each sliding cycle, forward and back, as one. A hose specimen, 3.5 inches long by 1.5 inches wide, was clamped to the fixture and mounted in the sliding sled (see Exhibit 2-8). The total weight of the mounting sled and specimen fixture was 509 grams. A 1-inch by 6-inch piece of 80-grit abrasive was cut and applied to the base pan of the unit to act as the abrasive surface. In addition, the test was run wet with water in the pan. Without the water, the sled/fixture 'chattered' and the water aided in keeping the abrasive grit clean by floating away the abraded hose material.

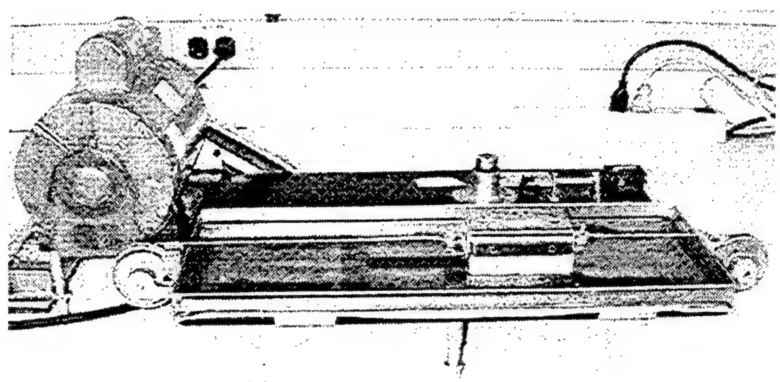


Exhibit 2-6: Gardner Abrasion Test Equipment

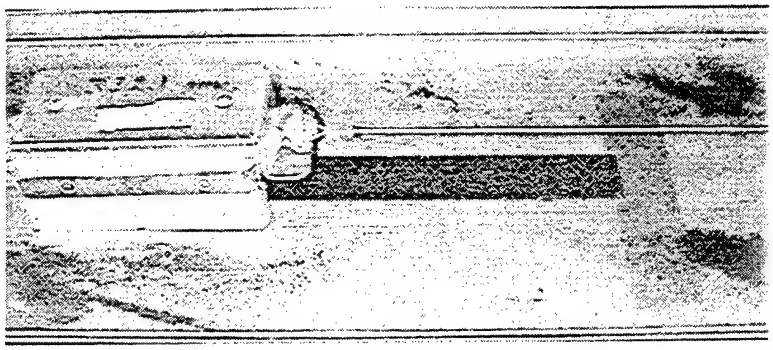


Exhibit 2-7: Gardner Abrasive Strip

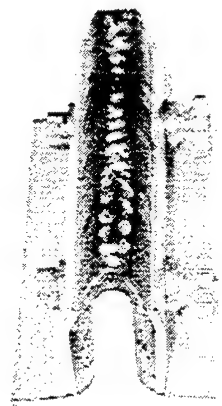


Exhibit 2-8: Gardner Abrasion Test Sled

The test was performed using a new abrasive strip for each specimen. In addition, if a hose went past 2,500 cycles, the abrasive strip was replaced. Failure, or the end of the test, was determined to be the point where a continuous band of fiber reinforcement was exposed across the entire length of the hose specimen. This point was picked because the forward and backward leading edges of the hose wear first due to the back and forth motion of the test equipment.

The test results are summarized in Exhibit 2-9. The new Durodyne hose provided the highest level of abrasion resistance followed by the Angus Chemicoil hose. These two hoses produced an abrasion resistance increase of 3.5 and 2.3 times respectively when compared with the fuel hose currently in use. One significant concern with the new Durodyne hose is the heavy weight value of 0.90 pounds per foot. Comparatively, the Angus Chemicoil hose weighs 0.37 pounds per foot.

Hose Manufacturer/ Type	Thickness (inches)	Abrasion Cycles	Run Time (minutes)
Angus Chemicoil	0.089	2,640	71.4
Durodyne – New	0.150	3,940	106.5
Angus Offshore	0.125	2,210	59.7
Current Fuel Hose	0.137	1,130	30.5

Exhibit 2-9: Gardner Abrasion Test Results

The Gardner abrasion test results provide data for one mode of hose failure: dragging the hose while in an extended flat position with a significant hose-to-ground contact area. A second, far more aggressive mode of hose failure occurs when the hose is dragged with a twist or kink which causes a very small area of hose to be in contact with the ground. This second mode of hose failure can occur in a very short dragging distance and is potentially more severe with a lay-flat hose than a collapsible hose due to cross-section geometry differences.

One approach to increase the abrasion resistance of any hose is to apply an abrasion resistant sheath to the outside diameter of the hose. This is commonly done with lay-flat fire hose to protect it from the harsh dragging induced abrasive environment typically encountered during use.

Exhibit 2-10 provides critical parameter information for nine types of potential abrasion resistant sheath materials.

Material	Abrasion Resistance	Ultraviolet Degradation	Rot Resistance	Fuels Compatibility	Cost Index	Total Score
Manila	2	4	1	1	5	13
Sisal	2	4	1	1	5	13
Cotton	2	4	1	1	5	13
Nylon	5	4	5	3	4	21
Polyester	5	4	5	3	4	21
Polypropylene	2	5	5	3	4	19
Kevlar	2	2	5	5	2	16
Spectra	5	2	5	5	1	18
Vectran	4	2	5	5	1	17

Note – Scale values are (1) = poor, (2) = fair, (3) = good, (4) = very good, (5) = excellent

Exhibit 2-10: Abrasion Resistant Sheath Material

As seen in Exhibit 2-10, nylon and polyester are the most appropriate materials for the ROLM hose sheath. Discussions with hose manufacturers confirmed that nylon and polyester are the two most common materials used in abrasion resistant sheaths. Samples of the two sheath materials were obtained and the weight of the nylon and polyester sheaths were both measured to be 0.23 pounds per foot.

Angus has completed a developmental program during which they fabricated and evaluated a hybrid hose that applies an abrasion resistant polyester sheath (nylon has the undesirable potential to absorb water) to the outside diameter of an off-the-shelf Chemicoil hose. This hybrid 3-inch hose has a total hose plus sheath weight of 0.37 + 0.23 = 0.60 pounds per foot (the current 2-inch hose weighs 0.59 pounds per foot). The new 3-inch Durodyne hybrid hose with an abrasion resistant polyester sheath would weigh 0.90 + 0.23 = 1.13 pounds per foot which makes their hybrid hose unacceptable for FARP operational use.

Durodyne and Angus delivered a 100-foot sample of their respective hoses to AFSOC where FARP personnel evaluated parameters such as abrasion resistance, hose weight, and hose handling characteristics. The Angus hybrid hose had the highest abrasion resistance and the lightest weight while both hoses exhibited good handling characteristics. Based on this in-field evaluation, the Angus hybrid hose was selected for use on the new ROLM Cart.

Discussions are underway with Angus to complete a second developmental program that uses a carbon-based conductive polyurethane polymer. This conductive polymer approach was suggested by Arthur D. Little, Inc. as an alternative to using conductive copper or stainless steel wires embedded in the hose to achieve a maximum allowable resistance of 1.0 ohms per foot of fuel hose. Use of the conductive polymer hose would eliminate the requirement of completing resistance checks on each section of hose prior to use. The recommended conductive polymer is manufactured by BF Goodrich and is sold under the trade name 'STAT-RITE E-1140'. Preliminary evaluations by Angus indicate that this alloy of STAT-RITE would meet the maximum allowable resistance value and could be extruded using their current manufacturing equipment and procedures.

2.4 Hose Reels

There are four motorized reels to store and deploy the hoses. All reels are the same model for interchangeability and standardization. The reel assembly is manufactured by Nordic Systems Inc. Series 3900 Model #EP5900-25-20X7-30 (see Exhibit 2-11). The 200-foot long feed hose reel from the MC-130 tanker is at the rear of the chassis and provides fuel to the pump. Two of the three output hose reels contain 240-foot hose lengths. The third output reel has a 100-foot long hose. There is a spare 240-foot hose underneath the cart in the storage drawer. All reels will be powered by a 2/3 hp explosion-proof motor rated at 12 volt DC (UL listed as a Class 1, Group D). In actual operation the motor consumes 20 Amps at 12 VDC (0.3 hp). The hose can be wound or unwound at three miles per hour (264 feet per minute). The reel frame is made of aluminum to reduce weight and corrosion-related maintenance. Each reel has a vertically-oriented manual rewind crank and a free wheeling clutch. A hose layer winding guide is available as an option and testing will determine if it is required. Each reel has a universal rotary union for a hose connection. Hoses are bolted to the fuel gooseneck and have a flange connection to the manifold at the other end. Each reel has a side-mounted control panel (Exhibit 2-12) with pushbuttons to control hose wind/unwind, fuel valve open/close, and a centrally mounted emergency stop push button.

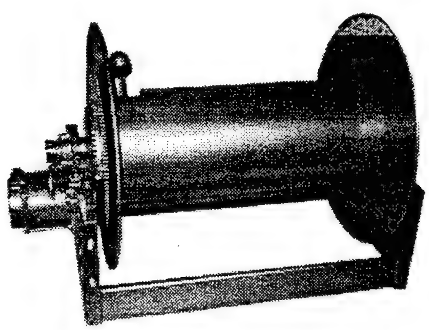


Exhibit 2-11: Motorized Hose Reel

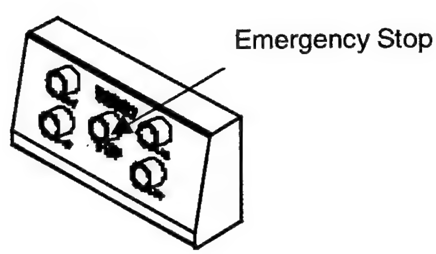


Exhibit 2-12: Hose Reel Control Panel

2.5 Pump

The dump pumps on-board the MC-130 tanker can transfer fuel from the integral tanks, the auxiliary tanks, and the forward and aft external tanks to the single point refueling (SPR) panel which is where the 200-foot FAM and ROLM Cart supply hose connects to the tanker aircraft.

Using the four main tanks, the maximum fuel transfer rate (as seen in Exhibit 2-1) is 298 gallons per minute. This value was used to size the pump on the ROLM Cart. (See Section 3.1 for a discussion on system function losses and pressure drops.)

There is a variety of pump types that have potential application on the ROLM Cart. Some pump types are more appropriate than others based on size, weight, or cost. For each pump type, several manufacturers were contacted and the most appropriate pump type and manufacturer is detailed in Exhibit 2-13.

Type	Manufacturer	Cost ($)	Weight (lbs)	Dimensions (L"xW"xH")	Shaft H.P. Required	R.P.M.	Material
Gear	Liquiflo	$17,300	200	28 x 18 x 20	24	3,500	Stainless
Rotary Vane	Blackmer	$1,749	88	17 x 14 x 10	12	950	Aluminum
Centrifugal/Vane	Gorman-Rupp	$4,287	238	26 x 17 x 20	14	3,000	Ductile Iron
Centrifugal	Gorman-Rupp	$1,490	80	22 x 12 x 12	11	3,000	Aluminum
Hose	Granzow	$32,000	10,000	90 x 27 x 84	30	34	Steel
Double Diaphragm	Graco	$1,418	182	24 x 17 x 41	40	N.A.	Aluminum
Piston	EP Industries	$6,800	175	32 x 11 x 11	9	700	Aluminum

Exhibit 2-13: Pump Comparison (300 gpm @ 33 psi system loss)

All pumps can be classified as either *dynamic* or *positive displacement*. The most common example of a dynamic pump is a centrifugal pump in which energy is continuously added to increase the fluid velocity so that the fluid pressure is increased resulting in fluid flow, similar to an air-moving fan.

Examples of positive displacement pumps include piston, gear, vane, and diaphragm, in which energy is periodically added by application of force to an enclosed fluid-containing volume, resulting in an increase in pressure which forces fluid flow through an exhaust valve (similar to an automotive engine).

Dynamic pumps have the advantage of low cost, high reliability, minimal weight, typical operating speeds up to 3,600 rpm that allow direct coupling to an engine, and simplified valves and controls to allow operation during the fueling and defueling activities. Unfortunately, dynamic pumps do not have the ability to efficiently pump liquid and air as they are designed for single-phase (liquid or air) operation.

Positive displacement pumps are typically larger, heavier, more expensive, require significantly more complex valving and controls, and they typically operate at low speeds which require a speed reducer between the engine and the pump, but they are relatively efficient at pumping liquid and/or air and therefore could be used to assist in the defueling of hoses.

The nature of the ROLM mission requires component simplicity and reliability. These factors, combined with the other advantages of a dynamic pump may eliminate further consideration of a positive displacement pump. The selected dynamic pump is a self-priming centrifugal style

manufactured by Gorman-Rupp Company (Model #03H1-B) as seen in Exhibit 2-14. This pump is manufactured from aluminum and weighs 77 pounds. The pump has a maximum output at 3,000 rpm (typical engine speed) of 375 gpm at 19 psi, or 300 gpm at 32 psi (maximum pump speed is 3,600 rpm). It requires a 9 horsepower engine at the 300 rpm output condition and can be direct coupled (does not require a speed reducer) to the engine. The pump will produce zero flow (stall) when the differential (inlet to outlet) pressure exceeds 48 psi (at 3,000 rpm). Once the inlet/outlet pressure differential drops below 48 psi (by opening a refueling nozzle), the pump will again begin to produce flow. The only control device required for fueling or defueling would be a pressure relief valve on the pump discharge line that would divert pump discharge flow back to the manifold when all refueling nozzles are closed.

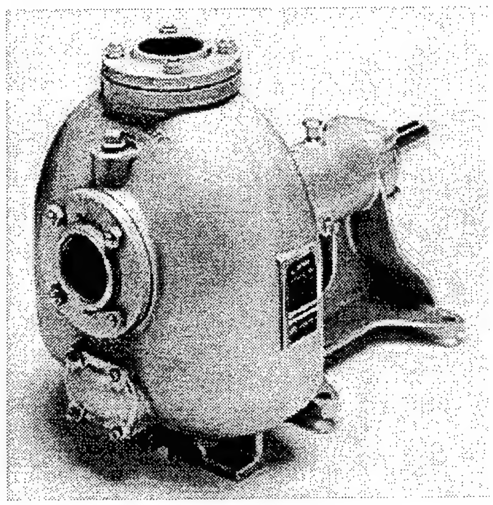


Exhibit 2-14: Self-priming Centrifugal-style Dynamic Pump

2.6 Engine

The engine required to drive the selected pump must operate with a JP-8 fuel source. The engine must also have an electric start system and be air-cooled for reliability and reduced maintenance, have a means for manual starting should there be a failure with the electric start system, and have a corrosion proof fuel tank.

Virtually any diesel engine can operate using JP-8 as a fuel source, but due to the lower energy (Btu) content of JP-8 versus diesel fuel, there is typically a 7% reduction in engine power output when using JP-8 fuel.

Fifteen diesel engine manufacturers were identified as having engines in the required horsepower range, all of which are compatible with JP-8 fuel. Only two manufacturers, however, were able to deliver all of the requirements. The engines from these two manufacturers have electric start, manual start backup, permanently mounted magnet generator (PMG) battery charging system, air-cooled engine, EPA and/or CARB certification, glow plug capability for low-temperature starting, and a maximum ambient operating temperature of 125°F. Additional engine-specific details are shown in Exhibit 2-15.

Parameters	Hatz	Lombardini
Continuous hp @ rpm with JP-8	13.3	17.1
Maximum Operating rpm	3,600	3,000
Charging System 14 V @ Amps	14	14
Model #	1D81Z-ES	12LD475-2
Weight (lbs.)	195	220
Unit Cost ($)	$3,247	$4,656

Exhibit 2-15: JP-8 Fueled Engines

The maintenance requirements for the Hatz and Lombardini engines are essentially identical. Engine selection is therefore based on weight and unit cost data. The Hatz model #1D81Z-ES engine is 25 pounds lighter and $1,400 less expensive than the noted Lombardini engine. The Hatz engine (see Exhibit 2-16) is more closely sized for the required horsepower output (using JP-8 fuel) and is therefore selected for use with the Gorman-Rupp centrifugal pump. The higher maximum rpm of the Hatz engine also provides greater potential pump flow and pressure output.

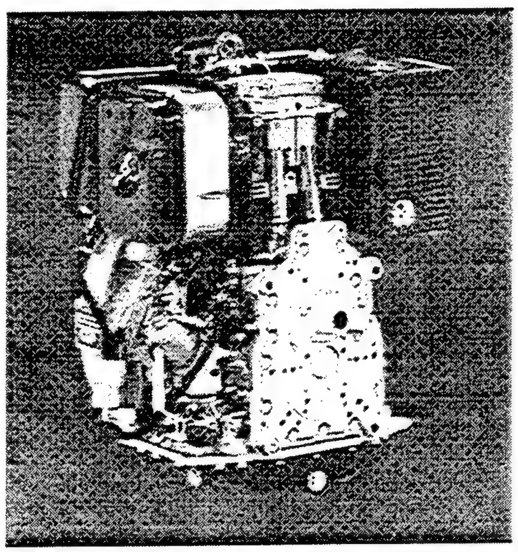


Exhibit 2-16: Hatz Model #1D817-ES Engine

2.7 Squeegee

A commonly used method of defueling hose is to use squeegee rollers to compress the deployed hose and displace the residual fuel back to the MC-130 tanker. At present, this operation is performed manually by pulling on the squeegee-mounted T-bar. This operation is very strenuous and time consuming because the current 300-foot hose is made of three hose sections with couplings every 100 feet. The squeegee must be removed and reattached at each hose coupling.

The new squeegee design incorporates a motorized drive unit to increase the rate of defueling and to reduce the amount of physical stress produced with the current squeegee hardware. By incorporating a sealed variable speed DC motor with rechargeable batteries, a newly designed squeegee will provide fast and easy defueling. The new design has a variable defueling speed (0 – 5 mph). At a speed of 3 mph (264 feet per minute), the longest hose (240 feet) can be defueled

in less than one minute. Should the drive unit motor fail, there is a freewheeling clutch for the squeegee to be pulled manually by the T-bar handle as is currently done.

The squeegee has two rollers to squeeze the hose (Exhibit 2-17). One roller is the driver and the other is the follower. The follower roller is hinged and swings out to allow insertion of the hose. A pair of steel latches keeps the rollers together under compression. If the hose encounters an obstacle (such as a small rock or twig), the steel latches have enough flexibility to prevent hose rupture or jamming, yet are stiff enough to prevent fuel from bypassing the rollers.

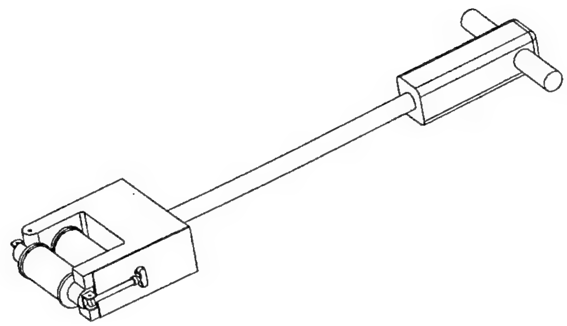


Exhibit 2-17: New Squeegee Design

The driver roller is connected to the motor with a slip clutch and a set of bevel gears. Any overload will cause the clutch to slip thus protecting the drive components. The new squeegee design utilizes lightweight aluminum components to minimize weight.

The battery powered motor drive unit is proposed to be an off-the-shelf battery powered drill that has proven field reliability and mass production affordability. A review of potential motor drive units is summarized in Exhibit 2-18. All of the models listed in Exhibit 2-18 have torque outputs significantly greater than the required 60-inch pounds. The battery from the motor drive unit is rechargeable using a 110-volt charging unit that typically provides a full recharge from a completely discharged state in approximately 45 minutes. As all of the battery powered motor drivers listed in Exhibit 2-18 meet the new squeegee requirements, the Panasonic model #EY6431NQKW was selected due to low cost and low weight considerations.

The significant difference between the motor drive units is the type of battery used to provide power. The two battery types are Nickel Cadmium (Ni-Cad) and Nickel Metal Hydride (Ni-MH). Ni-Cad batteries were first developed in the 1950s and have been the battery of choice for portable rechargeable applications. The power density of sub "C" size Ni-Cad batteries used in power tool applications has improved to the point where they can now store up to 2.4 Ah of energy. However, further advances with Ni-Cad batteries are expected to be minimal. Given the Ni-Cad battery energy storage limitation and environmental concerns about cadmium, manufacturers have developed Ni-MH batteries. These batteries can theoretically store about 40% more energy than Ni-Cad. The highest energy level of a power tool-size Ni-MH battery today is 3.0 Ah but future advances are expected to reach the 3.4 Ah level.

Make							
Makita	6343DWAE	5.5	$250	404	18	2.0	Ni-MH
Bosch	3960K-CC	6.2	$300	500	24	2.0	NiCad
Panasonic	EY6431NQKW	4.4	$200	390	15.6	3.0	Ni-MH
Milwaukee	0522-22	5.6	$260	400	18	2.0	NiCad
DeWalt	DW995K-2	5.6	$260	355	18	2.4	NiCad
Porter-Cable	9884	5.9	$270	390	19.2	2.0	NiCad
Hitachi	DS14DV	4.6	$200	304	14.4	2.0	NiCad
DeWalt	DW006K*	8.4	$300	550	24	1.7	NiCad

Exhibit 2-18: Battery-Powered Motor Drive Comparison

3. ANALYSIS

An essential task in this Delivery Order was to evaluate the improvements provided by the ROLM Cart when compared to the existing FAM Cart. The key comparison metrics included the following:

- System Frictional Losses – Theoretical calculation of the frictional losses allow understanding of FAM Cart limitations (and confirmation of flow rates) and proper sizing of the ROLM Cart pump and hoses to increase system efficiency.
- Life-Cycle Costs – Projected life-time costs to acquire, operate, deploy, maintain, and repair the equipment.
- Weight – Comparison of specific weight (that is the total weight of the cart divided by the fuel output in gallons per minute).
- Reliability – Expressed as Mean Time Between Failures (MTBF).
- Set-Up/Tear-Down Times – Based on field collected times for the FAM Cart and on operational estimates for the ROLM Cart.

In the subsections that follow, the analysis methodology used in this comparison is outlined and the results of the comparison are reported.

3.1 Friction Losses and Pressure Drops

Maximum flow rates for one, two, and three operational refueling points for the FAM Cart were measured by AFSOC and are presented in Exhibit 3-1.

Number of Points	Flow Rate/Point (gpm)	Total Flow Rate (gpm)
1	37	37
2	33	66
3	27	80

Exhibit 3-1: Maximum Flow Rates for the FAM Cart

The FAM Cart total flow rates are significantly less than the desired 300 gpm, and therefore require long refueling times for high fuel consumption aircraft such as fighters. A review and analysis of the FAM Cart equipment ensued and the results are discussed below for each significant component.

The pump used on the FAM Cart is a Gorman-Rupp self-priming centrifugal Model #83A1-530RT-X. This pump is direct-coupled to a Lombardini Model #6LD360RT7 engine with a maximum continuous output of 6.0 hp at 3,000 rpm when fueled with JP-8. The pump has a maximum output at 3,000 rpm of 378 gpm at 6 psi. At 80 gpm output, the pressure output is 32 psi. The pump will produce zero flow (stall) when the differential (inlet to outlet) pressure exceeds 34 psi (Exhibit 3-2).

The FAM Cart uses 2-inch collapsible hose with a total length of 900 feet (with an additional 10 feet of 2-inch rigid hose for defueling purposes). The frictional loss through this size/length of hose (with Cart mounted valves and manifold) at a flow rate of 80 gpm is calculated to be 31 psi. This calculated value is substantiated by the measured flow rate seen in Exhibit 3-1 and the pump output data of 80 gpm at 32 psi that converts to a pump efficiency of 37% (Exhibit 3-2).

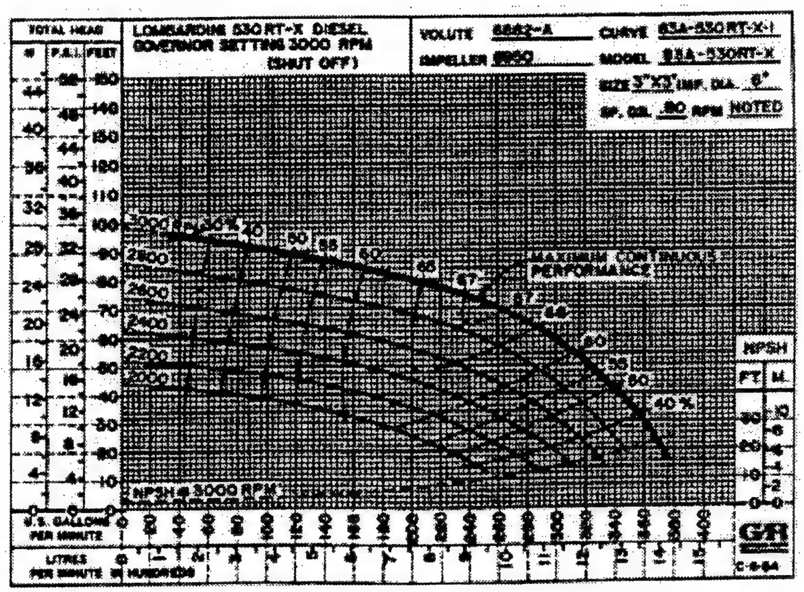


Exhibit 3-2: FAM Cart Pump Curve

The frictional loss through the proposed ROLM Cart using 3-inch hose (with cart-mounted valves and manifold) at a flow rate of 300 gpm is calculated to be 29 psi. The self-priming centrifugal pump (Gorman-Rupp Model #03H-B) selected has a maximum pressure output of 32 psi at 300 gpm which converts to a pump efficiency of 62% (Exhibit 3-3).

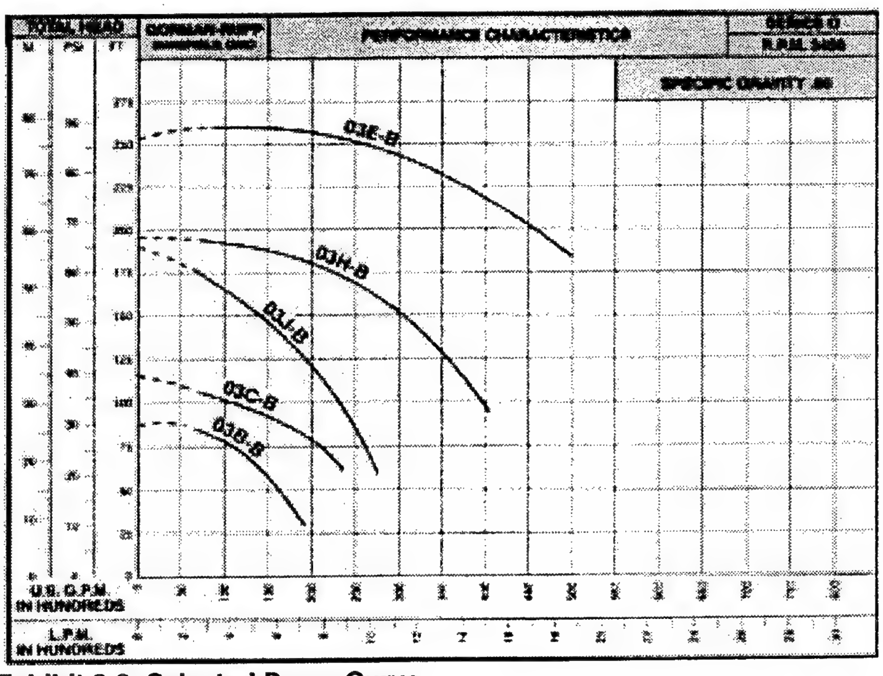


Exhibit 3-3: Selected Pump Curve

3.2 Life-Cycle Costs

A life-cycle cost analysis for a military application refueling cart typically consists of a summation of costs over a defined period of functional equipment life broken down into the following four categories:

- Acquisition
- Deployment
- Operation and maintenance (O&M)
- Refueling times

A discussion of the four categories follows.

3.2.1 Acquisition Cost

The FAM Cart acquisition cost for the Year 2000 was calculated by obtaining the bare acquisition cost (no hoses, nozzles, couplings, or shipping costs) of a FAM Cart procured in 1995 (obtained from Contract #NTP408AM, Order #94J601) at a cost of $134,183 and adding an annual equipment inflation factor of 5%. The calculated Year 2000 bare acquisition cost then becomes $171,200.

ROLM Cart bare acquisition costs were determined by contacting vendors and obtaining price quotations for all major components. In addition, engineering estimates were made for miscellaneous items such as plumbing, electrical, and mechanical hardware. The component quantities and unit costs along with manufacturing associated cost factors (obtained from the ACE-IT Life-Cycle Cost Model) are detailed in Exhibit 3-4 and calculate that the ROLM Cart bare acquisition cost is $145,000.

Component	Quantity	Unit Piece Part Delivered Cost $[1]	Total Piece Part Cost $	Fabrication & Testing $[2]	Engineering Change Orders (= 0.02 x Piece Part $)[4]	Training $ (= 0.011 x Piece Part $)[4]	System Engineering/Program Mgmt (= 0.26 x Piece Part $)[4]	Data (= 0.085 x Piece Part $)[4]	Initial Spares/Repair Parts (= 0.133 x Piece Part $)[4]	Fee (= 5%, applied to ECO, Training, SE/PM, and Data)	G&A (= 10%, applied to ECO, Training, SE/PM, and Data)	Material Handling Overhead (= 1.5%, applied to Piece Part $, and IS/RP)	Plant Wide Overhead (= 110%, applied to ECO, SE/PM, and Data)	Contractor Training Overhead (= 90%, applied to Training Costs)	Acquisition Cost $[5]
Front/Rear Axle & Drawbar	1	$6,400	$6,400	$0	$128	$70	$1,664	$544	$851	$120	$241	$109	$2,570	$63	$12,760
Frame with Manifold (Aluminum)	1	$16,500	$16,500	$0	$330	$182	$4,290	$1,403	$2,195	$310	$620	$280	$6,625	$163	$32,898
Drawer	1	$1,450	$1,450	$0	$29	$16	$377	$123	$193	$27	$55	$25	$582	$14	$2,891
Overhead Basket	1	$500	$500	$0	$10	$6	$130	$43	$67	$9	$19	$8	$201	$5	$997
Tie Down Hooks	10	$15	$150	$0	$3	$2	$39	$13	$20	$3	$6	$3	$60	$1	$299
Hose Reel, Motor, Clutch	4	$3,340	$13,360	$3,120	$267	$147	$3,474	$1,136	$1,777	$251	$502	$227	$5,364	$132	$29,757
Centrifugal Pump #03H1-B	1	$864	$864	$520	$17	$10	$225	$73	$115	$16	$32	$15	$347	$9	$2,243
Engine #1D81Z-ES	1	$3,350	$3,350	$1,040	$67	$37	$871	$285	$446	$63	$126	$57	$1,345	$33	$7,719
Battery (12V)	2	$90	$180	$260	$4	$2	$47	$15	$24	$3	$7	$3	$72	$2	$619
Hard Plumbing	1	$1,500	$1,500	$5,400	$30	$17	$390	$128	$200	$28	$56	$25	$602	$15	$8,391
Isolation Valves (Motorized)	4	$880	$3,520	$520	$70	$39	$915	$299	$468	$66	$132	$60	$1,413	$35	$7,538
Fuel/Defuel Valve #9048B	1	$1,370	$1,370	$260	$27	$15	$356	$116	$182	$26	$52	$23	$550	$14	$2,991
Pressure Relief Valve	1	$400	$400	$195	$8	$4	$104	$34	$53	$8	$15	$7	$161	$4	$993
Instrumentation/Panel	1	$4,000	$4,000	$1,560	$80	$44	$1,040	$340	$532	$75	$150	$68	$1,606	$40	$9,535
Electricals	1	$2,200	$2,200	$4,860	$44	$24	$572	$187	$293	$41	$83	$37	$883	$22	$9,246
Hardware (straps, latches, etc.)	1	$100	$100	$3,120	$2	$1	$26	$9	$13	$2	$4	$2	$40	$1	$3,319
Fire Extinguisher (20 lb)	5	$110	$550	$625	$11	$6	$143	$47	$73	$10	$21	$9	$221	$5	$1,722
Spray Water Bottle (5 gallon)	1	$45	$45	$130	$1	$0	$12	$4	$6	$1	$2	$1	$18	$0	$220
Tool Box	1	$40	$40	$130	$1	$0	$10	$3	$5	$1	$2	$1	$16	$0	$210
Squeegee (Motorized)	3	$1,500	$4,500	$1,680	$90	$50	$1,170	$383	$599	$85	$169	$76	$1,807	$45	$10,652
Complete ROLM Cart	1	-----	**$60,979**	**$23,420**	**$1,220**	**$671**	**$15,855**	**$5,183**	**$8,110**	**$1,146**	**$2,293**	**$1,036**	**$24,483**	**$604**	**$145,000**

[1] Costs obtained from vendors quotes and engineering estimates (includes shipping to fabrication facility)

[2] Estimated by designers

[3] Delivery from Cambridge to Hurlburt Field via Consolidated Freightways (DoD rate)

[4] Factor obtained from Air Force Cost Center

[5] Acquisition Cost $ = Sum of Columns D through P

Exhibit 3-4: ROLM Cart Acquisition Costs

3.2.2 Deployment Cost

Refueling cart deployment costs are unknown since the quantity and deployment distance of missions haven't been quantified by the USAF. The FAM and ROLM Cart dimensions and weights are summarized in Exhibit 3-5 and show that both carts have very similar footprint and weight specifications which make it reasonable to assume that they would have very similar deployment costs.

Specifications	FAM Cart	ROLM Cart
Footprint (ft^2)	51	66
Weight (lbs)	2,950	3,250

Exhibit 3-5: ROLM and FAM Cart Deployment Specifications

3.2.3 Operation and Maintenance (O&M) Cost

Operation and maintenance (O&M) costs are composed of manpower, operating, preventive maintenance, and corrective maintenance costs.

Manpower costs are the dominant contributor to O&M costs. Manpower requirements were reviewed early in the program and the Air Force determined that due to mission related safety issues, no manpower reductions would be allowed with ROLM.

Operating costs are defined as 96% fuel costs and 4% oil and lubrication related costs. Engine fuel consumption is calculated to be 3.8 pounds per hour for FAM, and 5.9 pounds per hour for ROLM. So assuming a JP-8 cost of $0.65 per gallon, the FAM and ROLM Carts would consume $0.38 and $0.59 worth of fuel respectively per operating hour.

Preventive and corrective maintenance costs are each comprised of replacement parts and waste disposal costs. Preventive maintenance activities include lubricating oil changes, air/oil filter changes for the engine, and maintaining chassis tire pressure. Corrective maintenance activities are based on component reliability and may include correcting corrosion, or the replacement of items such as lightbulbs, batteries, etc. Maintenance records supplied by AFSOC document the annual preventive and corrective maintenance costs at $440 per cart. The FAM Cart uses older and less reliable components while the ROLM Cart uses newer (more reliable) components but has a greater parts count due to the electrified components. In summary, the relative simplicity and similarity of the FAM and ROLM Cart based equipment indicates that the projected maintenance costs would be very similar.

3.2.4 Refueling Times

The time required to transfer fuel from the MC-130 tanker to a recipient aircraft also has an impact on a cart's life-cycle cost. The FAM Cart has a maximum fuel transfer rate of 80 gpm as seen in Exhibit 3-1. The ROLM Cart has a maximum fuel transfer rate of 300 gpm. The MC-130 tanker and recipient aircraft keeps their engines running during the refueling operation so fuel is continually consumed. The longer it takes to refuel an aircraft, the more fuel is consumed.

An analysis completed by Captain David Sanford (AFRL/HESS) concluded that refueling an MH-53 with a ROLM Cart is approximately 14 minutes while the current FAM Cart is 57 minutes would save $557 in fuel consumption costs based on a fuel cost of $0.62 per gallon (Appendix B).

3.3 Weight

The ROLM Cart is estimated to weigh 3,250 lbs as seen in Exhibit 3-6. This weight was determined by collecting vendor data for items such as hose, valves, pump, engine, chassis, etc., and by calculating the weights of fabricated items such as the manifold, electrical components, and internal plumbing. Aluminum was selected for the chassis, hose reels, pump, manifold, and internal plumbing because it reduces the overall cart weight and minimizes corrosion-related maintenance issues.

Component	Quantity	Unit Weight (lbs)	Total Weight (lbs)
Chassis	1	-----	-----
Front/Rear Axle & Drawbar	1	500	500
Frame with Manifold (Aluminum)	1	460	460
Overhead Basket	1	30	30
Tie Down Hooks	10	1	10
Hose 3" (ft)	780	0.6	468
Hose 3" Spare (ft)	240	0.6	144
Hose Reel, Motor, Clutch (200 ft)	1	160	160
Hose Reel, Motor, Clutch (100 ft)	1	160	160
Hose Reel, Motor, Clutch (240 ft)	2	160	320
Hose Fittings at Reel	4	3	12
Refueling Nozzles (3 of each style)	3	18.5	55.5
Centrifugal Pump #03H1-B	1	77	77
Engine #1D81Z-ES	1	195	195
Battery (12V)	2	58	116
Hard Plumbing	1	60	60
Isolation Valves (Motorized)	4	24.5	98
Defuel Valve #9048B+Actuator	1	24	24
Pressure Relief Valve	1	14	14
Instrumentation/Panel	1	35	35
Electricals	1	30	30
Hardware	1	25	25
Fire Extinguisher (20 lb)	5	26	130
Spray Water Bottle (5 gallon)	1	44	44
Tool Box	1	40	40
Squeegee (Motorized)	3	14	42
		Total =	**3,250**

Exhibit 3-6: ROLM Cart Weight Table

The existing FAM Cart has a comparable operational weight of 2,950 lbs as stated in Technical Order #37A9-7-2-1.

The specific fuel output cart output in gpm/cart weight of the ROLM Cart is 300/3,250 = 0.092. The specific fuel output/cart weight of the FAM Cart is 80/2,950 = 0.027. Therefore, the specific weight output realized with the ROLM Cart is more than three times higher than the FAM Cart. The data are summarized in Exhibit 3-7.

	ROLM Cart	FAM Cart
Total Cart Weight (pounds)	3,250	2,950
Fuel Output (gpm)	300	80
Specific Fuel Output (gallons/pounds)	0.092	0.027

Exhibit 3-7: Cart Specific Weights Comparison

3.4 Reliability

The focus in the context of early system design was on "high-level" analyses to support comparative reliability assessments of alternative concepts. As design refinement progressed, the analyses were updated to account for the additional design details.

3.4.1 Approach

Estimates for system reliability were developed by combining estimates for individual components into system estimates using standard methods for reliability assessments. All components are treated on the basis of the 'mid-life' period of their life-cycle, with constant failure rates over time. 'Infant mortality' and 'wear-out' were not considered for this analysis. The underlying assumption is that the useful 'mid-life' period is long in comparison with the other periods, so the bulk of the product life is well approximated. Such constant failure rate assumptions are commonly used in military reliability assessments. Given this constant failure rate assumption, the failure rates of individual components may be added to produce an estimate of the system failure rate and that the mean time between failures (MTBF) is the reciprocal of the failure rate.

A piece-part reliability estimate was completed for both the FAM and ROLM Carts. The *Non-Electronic Parts Reliability Data (NPRD-95)* reference source was used for all components. NPRD-95 was compiled by the Reliability Analysis Center at Rome Laboratory, Griffiss AFB, and is the most detailed mechanical and electro-mechanical reliability data source available and is therefore frequently used in military reliability assessments. All failure rate values were obtained or adjusted to a 'Ground Mobile' operating environment which is the operational mode of the FAM and ROLM Carts. 'Ground Mobile' is defined simply as 'equipment installed on wheeled or tracked vehicles'.

Exhibit 3-8 details the reliability of the FAM Cart. As expected, the FAM Cart is a very reliable system since it has a minimal number of components (e.g. no hose reels) and no electrical components (Note: reliability of the hose has not been calculated due to

variability in the application environment). The overall failure rate per million hours of usage is estimated to be 798 and therefore the MTBF is calculated to be 1,254 hours.

Component	Quantity	Ground Mobile Unit Failure Rate per 10^6 Hours	Quantity x Unit Failure Rate per 10^6 Hours
Front Axle (steering)	1	114.6	114.6
Pintle Assembly	1	0.5	0.5
Rear Axle	1	9.5	9.5
Frame (aluminum)	1	0.2	0.2
Mechanical Parking Brake Assembly	1	4.3	4.3
Hose (2')	900	N/A	N/A
Refueling Nozzles (lot of 9)	1	21.5	21.5
Pump (centrifugal)	1	12.1	12.1
Shaft Coupling	1	10.0	10.0
Engine	1	295.5	295.5
Butterfly Isolation Valve, NC	4	3.6	14.3
Defuel Valve	1	19.9	19.9
Valve Lever Assembly	5	2.3	11.5
Linkage Assembly	5	54.9	274.3
Pressure Relief Valve	1	8.8	8.8
System Plumbing	1	0.7	0.7
			Failures per Million Hours of Use = 798
			Mean Time Between Failures (hours) = 1,254

Exhibit 3-8: Reliability Evaluation for FAM Cart

As expected, the estimated theoretical failure rate for the ROLM Cart is higher than FAM due to the increased quantity and complexity of the system which contains electrical automation including hose reels, valves, push-buttons, and switches. The ROLM Cart reliability estimate does not take into account the extensive application of manual activation devices. These devices include a manual geared hand-crank to start the engine, levers or hand-wheels to actuate all valves, and hand cranks to move all hose reels to allow for manual operation should the cart lose electrical power. If electrical power were to completely fail, the cart would still be completely useable due to these manual activation devices, so the functional reliability of ROLM is identical to that of FAM. The estimated number of failures per million hours of use for the ROLM Cart with the full electrical system is estimated to be 3,826 which calculates to an MTBF value of 261 hours (Exhibit 3-9).

Component	Quantity	Ground Mobile Unit Failure Rate per 10^6 Hours	Quantity x Unit Failure Rate per 10^6 Hours
Front Axle (steering)	1	114.6	114.6
Pintle Assembly	1	0.5	0.5
Rear Axle	1	9.5	9.5
Frame (aluminum)	1	0.2	0.2
Mechanical Parking Brake Assembly	1	4.3	4.3
Hose (3')	780	N/A	N/A
Hose Reel, Motor, Clutch (200')	1	21.9	21.9
Hose Reel, Motor, Clutch (100')	1	21.9	21.9
Hose Reel, Motor, Clutch (240')	2	21.9	43.7
Hose Reel Swivel Fittings	4	502.8	2011.1
Hose Reel Motor Switch	4	14.0	55.9
Refueling Nozzles (lot of 9)	1	21.5	21.5
Pump (centrifugal)	1	12.1	12.1
Shaft Coupling	1	10.0	10.0
Engine	1	295.5	295.5
Battery (12V)	2	20.5	41.0
Butterfly Isolation Valve, NC	4	3.6	14.3
Valve Actuator, 12V Electrical	4	165.4	661.5
Valve Actuator Switch	4	14.0	55.9
Defuel Valve	1	19.9	19.9
Valve Actuator, 12V Electrical	1	165.4	165.4
Valve Actuator Switch	1	14.0	14.0
Pressure Relief Valve	1	8.8	8.8
Vacuum Break Valve	1	8.8	8.8
Control Panel Instrumentation			
Engine Start/Stop Switch	1	14.2	14.2
Pressure Gauge	2	1.0	2.1
NVG Lighting	1	16.2	16.2
Emergency Shutdown Push-Button	1	8.1	8.1
System Electrical Wiring	1	172.7	172.7
System Plumbing	1	0.7	0.7
			Failures per Million Hours of Use = 3,826
			Mean Time Between Failures (hours) = 261

Exhibit 3-9: Reliability Evaluation for ROLM Cart

3.5 Set-Up/Tear-Down Times

The system set-up time for the FAM and ROLM Carts are estimated to be approximately the same as there are only minor procedural differences. The system tear-down time for the ROLM Cart is estimated to be significantly less than the time required for the FAM Cart.

The FAM Cart set-up (Exhibit 2-3) procedure and time requirements are detailed in Exhibit 3-10. Exhibit 3-11 shows FAM Cart hose deployment.

Step	Task	Time (min.)
1	Connect hose to tanker SPR panel	0.3
2	Push cart 200 feet from tanker while deploying hose	1.25
3	Deploy 300-foot discharge hose in trident pattern	3.5
4	Deploy 100-foot discharge hose in trident pattern	1.5
5	Deploy 300-foot discharge hose in trident pattern	3.5
6	Move fire and water bottles from cart to refuel points	0.75
	Total	**10.8**

Exhibit 3-10: FAM Cart Set-up Times

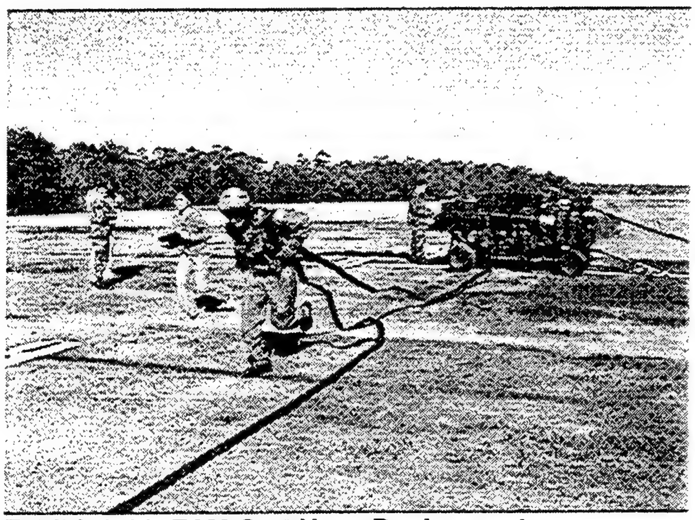


Exhibit 3-11: FAM Cart Hose Deployment

Adding the time requirements finds the total FAM Cart set-up time to be just under 11 minutes.

The ROLM Cart set-up has a different geometry that requires shorter outside discharge hose lengths (Exhibit 2-4) but maintains the 200-foot spacing between refueling points. The set-up procedure and time requirements are detailed in Exhibit 3-12.

Step	Task	Time (min.)
1	Connect hose to tanker SPR panel	0.3
2	Push cart 200 feet from tanker while deploying hose	1.25
3	Deploy 240 foot discharge hose in modified trident pattern	2.7
4	Deploy 100 foot discharge hose in modified trident pattern	1.5
5	Deploy 240 foot discharge hose in modified trident pattern	2.7
6	Move fire bottles from cart to refuel points	0.75
	Total	**9.2**

Exhibit 3-12: ROLM Cart Set-up Times

Adding the time requirements finds the total ROLM Cart set-up time to be just over nine minutes.

FAM Cart tear-down times were measured by AFSOC at up to 35 minutes. The bulk of the tear-down time was consumed in defueling and folding (restowing) the hoses (Exhibits 3-13 and 3-14 respectively) as these operations require two people each.

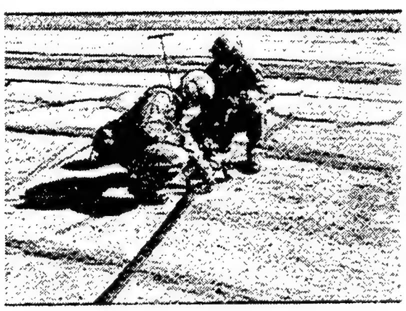


Exhibit 3-13: Hose Defueling

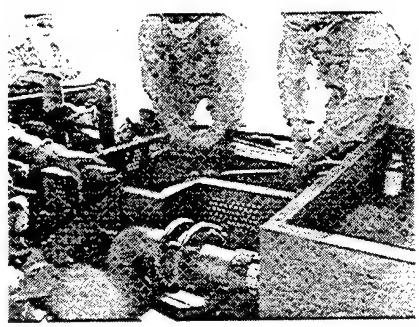


Exhibit 3-14: FAM Cart Hose Storage

With a maximum hose length of 100 feet, there are three sets of couplings on a 300-foot discharge hose and couplings slow the squeegee defueling process. Once defueled, the hoses must be folded into their storage baskets before the cart is pushed back to the tanker aircraft. Exhibit 3-15 provides details of the FAM Cart tear-down procedure and time requirements.

Step #	Task	Time (min.)
1	Position fuel/defuel valve in defuel position	0.25
2	Close isolation valve	0.25
3	Squeegee discharge hoses*	14
4	Shut down engine	0.25
5	Squeegee 200-foot supply hose	4
6	Stow squeegees	1
7	Stow four hoses into baskets	12
8	Push cart back onto MC-130 tanker	3
	Total =	**34.8**

* Squeegee operation requires two people, therefore lines cannot be defueled simultaneously.

Exhibit 3-15: FAM Cart Tear-down Procedure

The ROLM Cart eliminates the couplings that are required for the existing FAM cart (see Exhibit 3-16) by utilizing continuous length hoses and incorporates motor-driven hose reels to reduce tear-down time. The squeegee has also been redesigned and incorporates a variable-speed motor drive to reduce the physical requirements of the existing squeegee and since the operation can be completed by one person, it reduces the time requirement.

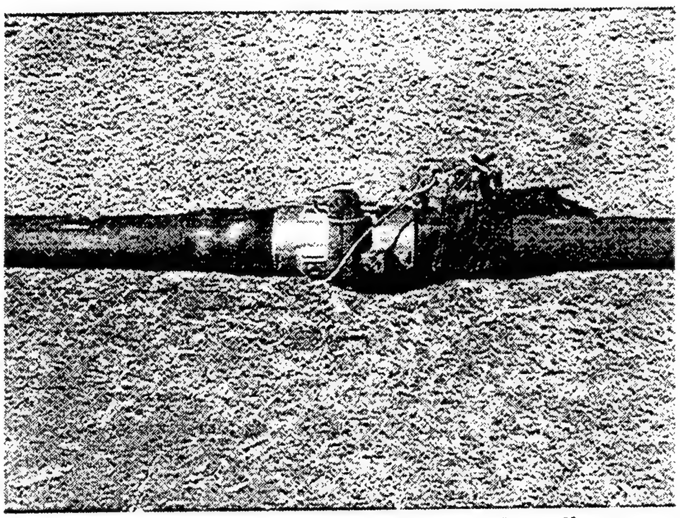


Exhibit 3-16: Existing FAM Cart Coupling

These system design changes are estimated to provide a tear-down time of about 14 minutes as seen in Exhibit 3-17.

Step #	Task	Time (min.)
1	Position fuel/defuel valve in defuel position	0.25
2	Close isolation valve #1	0.25
3	Squeegee discharge hoses (simultaneously)*	3
4	Shut down engine	0.25
5	Squeegee 200 foot supply hose	2
6	Stow squeegees	1
7	Rewind four hoses onto reels	4
8	Push cart back onto MC-130 tanker	3
	Total =	**13.8**

* Squeegee operation requires only one person, therefore lines can be defueled simultaneously.

Exhibit 3-17: ROLM Cart Tear-down Procedure

4.0 Conclusions/Recommendations

The main tasks were to define ROLM Cart requirements, develop conceptual level drawings, fabricate a scale model, and complete an engineering analysis of the new design.

The key accomplishments were as follows:

- Collected and prioritized requirements
- Developed a detailed specifications table which incorporated input from all FAM Cart users
- Analyzed specifications and requirements to develop new cart concepts
- Developed a conceptual ROLM design which responded to the requirements
- Created Computer Aided Design (CAD) drawings
- Fabricated a scale model of the conceptual design
- Completed a detailed analysis of system frictional losses, pressure drops, life-cycle costs, cart weight, reliability, and set-up/tear-down times

Our analysis indicates that maximum flow rates will be improved from 80 gpm to at least 300 gpm[1] by selecting properly sized transfer hoses and resizing the pump/engine. This represents a 300% fuel flow rate increase. Currently, Headquarters Air Force Special Operations Command (HQ AFSOC), a component of United States Special Operations Command (USSOCOM), has issued a moratorium on three-point FARP operations due to the excessive time to refuel aircraft. ROLM technologies will allow the refueling of three aircraft simultaneously and correct a critical mission deficiency. Individual aircraft refueling times will be reduced 75%. Cart tear-down times will be reduced from 35 minutes to 14 minutes by using motorized hose reels and a battery powered squeegee; thus, improving operational exfiltration times and increasing personnel and equipment force protection.

We recommend that the ROLM program continue with a Proof-of-Concept Fabrication and Testing Delivery Order. The objectives of the Proof-of-Concept task would be to perform key component and system-level demonstrations of the following components:

- Squeegee
- Hose
- Hose reel
- Hose-to-hose-reel interactions
- Pump/engine
- Aircraft refueling

Selected cart components would then be procured, fabricated, and tested to ensure that ROLM system performance meets the user specified requirements, including:

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[1] MC-130 tanker aircraft dump pump output flow rates and pressure drop data acquisition will be conducted in mid-September 2000 at Hurlburt Field. Collection of this data will allow calculation of the maximum ROLM Cart flow rate output.

- System set-up time
- Aircraft refueling rate
- System tear-down time

Appendix A: Requirements Table

	FAM Cart	ROLM	Comments
Equipment/ Performance			
Flow rate	80 gpm (with a 3-pt system)	300 gpm (with a 3-pt system)	
Fuel type	JP-8	JP-8	
Fuel tank	1-gallon steel tank	2-gallon plastic tank, corrosion proof, fill to 50% tank capacity	
Pump/Engine	Gorman-Rupp 80 gpm centrifugal/1-cylinder, air-cooled 6.0 hp Lombardini diesel engine, rope start	Gorman-Rupp 300 gpm self-priming centrifugal/1-cyclinder, air-cooled 13.3 hp Hatz diesel engine, electric start, handcrank backup	
Defuel Pump	External 28 VDC, 0.5 hp electric motor, 50 gpm pump with manually powered squeegee	Uses cart mounted pump (above) with battery powered squeegee	
Couplings	Unisex dry breaks to connect hoses every 100 ft	Unisex dry breaks at hose reels and nozzle ends only	
Hose	Durodyne collapsible hose; black neoprene synthetic rubber cover; Max. working pressure = 100 psi. 10' x 2" rigid defuel hose.	Angus Chemicoil lay-flat hose; polyurethane with integral abrasion-resistant sheath; Max. working pressure = 300 psi	
Hose dimensions	2" diameter, maximim hose length = 100 ft. Tanker-to-cart hose (1) x 200', Cart-to-center-point hose (1) x 100', Cart-to-side-point hoses (2) x 300' All hoses greater than 100' require couplings for extension. Spare hose (1) x 100'.	3" diameter, maximum hose length = 240 ft. Tanker-to-cart hose (1) x 200', cart-to-center-point hose (1) x 100', cart-to-side-point hoses (2) x 240'. Spare hose (1) x 240'.	
Hose configuration	Trident	Modified trident	
Hose storage	4 removable baskets	4 motorized hose reels (Nordic) with manual handcrank backup; Spare hose in drawer under chassis	
Hose evacuation	Separate defuel pump (see above), manual squeegee	Cart mounted pump (see above), battery powered squeegee	
Brakes	Manual spring-loaded parking brakes with no ability to hold cart stationary on 15 degree sloped ramp	New mechanical parking brakes will hold cart stationary on 15 degree sloped ramp	
Movement	Up to 4 personnel, 1 person at front of cart pulling rope attached to tow bar, others pushing cart behind	Up to 4 personnel, 2 at front with retractable pushbar with safety detent, 2 pushing from behind	
Manifold fueling point outlets	Up to 3 outlets	Up to 3 outlets	
Controls	5 levers to select refueling or hose evacuation modes	One master control panel: 2-position toggle buttons for fuel/defuel, engine on/off, and emergency stop button. Control panel at each hose reel: 2-position toggle buttons for reel unwind/rewind, fuel valve open/close, and emergency stop button.	
Gauges	Pressure/vacuum gauge on pump inlet and manifold	Pressure/vacuum gauge* on pump inlet and manifold; JP-8 engine fuel-level gauge	* All pressure gauges will be illuminated and IR-readable
Squeegees	Manually-pulled 2-roller assembly; rollers connected by pins; attached to 3' handle; fits 2" diameter hose	Battery-operated* with tensioning rubber T-straps connecting 2 rollers (pinless for ease of use); fits 3" diameter hose; Variable speed from 0-5 MPH. Telescoping handle from 2' - 3'.	* Manual pull is possible in case of battery failure

Appendix A: Requirements Table (continued)

Induced environmental conditions			
Shock	MIL-STD-810E (air, ship, rail, truck)	same	
Vibration	MIL-STD-810E (air, ship, rail, truck)	same	
Noise	Minimize noise level at control panel	same	
Natural environmental conditions			
Operating temperature	Range -25F to 130F	same	
Storage temperature	unknown	Recommended range -40 to 140 F	
Humidity	unknown	0-100%	
Pressure/rapid decompression	N/A	N/A	
Rainfall	IAW MIL-STD-810	same	
Wind resistance	45 mph	same	
Sand and dust	IAW MIL-STD-810	same	
Salt laden moisture	IAW MIL-STD-810	same	
Solar radiation	IAW MIL-STD-810	same	
Fungus (tropical)	IAW MIL-STD-810	same	
Operating altitude	sea level to 5,000 ft	same	
Operating angle	unknown	Full capacity when tilted in any position at 5 degrees from the horizontal	
Cold start capability	-25F	-25F	
Safety			
Emergency Shutdown	1 step (close valve), close the offload valve switch, shuts off fuel flow with emergency shutoff lever at cart inlet	1 push button places entire system in fail-safe mode	
EMI radiation/susceptibility	MIL-STD-461 200W/m^2 flight deck 50W/m2 hangar deck	same	
System safety	identify safety issues IAW MIL-STD-882; conform to standards of safety and best commercial practices	same	
Electrical safety	No electrical system	Electrical system is explosion-proof (see below)	
Explosion safety	N/A	NEMA 7, Class 1, Division II	
Fire safety	Five 20 lb dry chemical fire extinguishers	same	
Personnel washdown	Two 5-gallon water jugs	One 5-gallon water jug with spray wand	
Infrared Chemlight	Placed on water jugs to indicate refuel point is ready	same	
HSI/Human Factors			
Clothing/garments	100% nylon, Gore-tex for servicing with JP-8	same	
Handwear	Nomex flight gloves	same	
Headgear	Helmet	same	
Eye Protection	Dust goggles or NVGs (as needed)	same	
NBC/CW use	not in training, but wartime	same	
Night use	NVG compatible	same	
Displays and interfaces	daytime readable	daytime and IR-readable	
Labeling	daytime readable	daytime and IR-readable	
Number of personnel to move	4	same	
Number of personnel to operate	4	same	
Capabilities within existing skill set	Personnel must pass physical requirements testing	same	
Time to train	4 day training course, 1-2 hours per training mission	same	

Appendix A: Requirements Table (continued)

Maintainability			
Maintenance	MIL-STD-1472	same	
Common tools	standard tools	same	
Tools required for 30 days maintenance?	toolbox - no special tools	same	
Accessibility to major components and servicing ports	1st level repair	same	
Suppportability			
People required for 30 days maintenance	N/A	N/A	
Fuel usage for 30 days maintenance	N/A	N/A	
Spare required for 30 days maintenance	filter/oil	same	
Standard parts	Maximize NSN parts from DLA	same	
Durability	20 years	same	
Reliability and Availability			
MTBF	1,222 hours	same	
MTBPM	After each use - 6 months	same	
MTTR (PM)	1 hour	same	
MTTR (CM)	N/A	N/A	
Operational availability	95% availability	same	
Drainage	Fuel tank drain valve mounted on frame below fuel tank	Manual drain on fuel tank for maintenance and draining of water contamination	
Low point drain	Unknown	Low point drain on cart plumbing	
Operational availability	5-8 missions/month; 1 hour/mission	same	
Deployability and Transportability			
Tiedown rings/winches	Front/rear tiedown rings at 3,800 lbs; side rings at 1,900 lbs; tow bar at front of cart, winching ring center aft of cart	Front/rear/side ring capacities all 5,000 lbs; Maximum strength ring capacities will be labeled, maximum tow speed at 20 mph will also be labeled; cart basket also with tiedown rings	
Ground transportability	Maximum tow speeds: 10 ph on paved roads, 5 mph on dirt/gravel roads	Maximum 20 mph tow speed	
Air transportability	MIL-STD-1791	same	
Weight	2,950 lbs (operational), 1,250 lbs (no hose)	3,250 lbs	
Footprint	130"L (towbar up) x 57"W x61"H	124"L (towbar up) x 60"W x 55"H	
Cube	377 cu. ft.	250 cu. ft.	
Ground clearance	8 1/8"	11"	must allow loading into all transports

Appendix A: Requirements Table (continued)

Environmental compliance			
Ozone depleting substances	none	none	
Hazardous materials	Lubrication oil, JP-8	same	
Emissions	Non EPA-certified	EPA/CARB-certified	
Waste stream	Lubrication oil, filters	same	
Survivability			
FOD	must not eject or produce foreign objects	zero FOD	
Number of water collection points (NBC decon)	TBD	TBD	
Documentation			
Equipment markings	unknown	15	
Technical orders required for maintenance	T.O. 37A9-7-2-1	1	
Interoperability and Modularity			
Multimission design series capable	N/A	N/A	
Modularity	N/A	N/A	
Cost			
Base cart procurement cost	$171,200	$145,000	
Maintenance cost (annual)	$440	$460	
Deployability cost	N/A	N/A	
Disposal cost	Unknown	same	

Appendix B

Forward Area Refueling Point (FARP) Fuel Cost Computation:

Assume 3-Point FARP
Receiver Aircraft

Aircraft	Designation	Max Fuel Capacity/lbs	Max Fuel Capacity/gal	Fuel Burn Rate/lbs/hour	Fuel Burn Rate/GPH	Fuel Burn Rate/min
Pavelow	MH-53	8450	1261.19403	2300	343.2835821	5.721393035
Pavehawk	MH-60	2250	335.8208955	1150	171.641791	2.860696517

Aircraft	Refuel Resting Aircraft/min	Hot Refuel Aircraft/min	Fuel Price FY00	Fuel Price FY01	FY00 Fuel Costs	FY01 Fuel Costs
Pavelow	46.71088999	56.60908854	0.6221	1.014	950.85	1549.84
Pavehawk	12.43781095	13.75561844	0.6221	1.014	231.05	376.60

New FAM Cart Configuration
Assume 100 GPM/3-Point FARP

Aircraft	Refuel Resting Aircraft/min	Hot Refuel Aircraft/min	Fuel Price FY00	Fuel Price FY01	FY00 Fuel Costs	FY01 Fuel Costs
Pavelow	12.6119403	13.33351897	0.6221	1.014	829.48	1352.02
Pavehawk	3.358208955	3.454277122	0.6221	1.014	214.89	350.26

Aircraft	FY00 Fuel Cost Savings/Per Aircraft Using New FAM Cart	FY01 Fuel Cost Savings/Per Aircraft Using New FAM Cart
Pavelow	121.37	197.82
Pavehawk	16.16	26.34

Tanker Aircraft

Aircraft	Designation	Max Fuel Capacity/lbs	Max Fuel Capacity/gal	Fuel Burn Rate/lbs/hour	Fuel Burn Rate/GPH	Fuel Burn Rate/min
Talon II	MC-130	55000	8208.955224	6500	970.1492537	16.16915423

	Hot Refuel Aircraft/min	Talon II Fuel Burn Rate (GPM)	Fuel Price FY00	Fuel Price FY01	FY00 Talon II Fuel Costs	FY01 Talon II Fuel Costs
Pavelow	56.60908854	915.3210833	0.6221	1.014	569.42	928.14
Pavehawk	13.75561844	222.4167161	0.6221	1.014	138.37	225.53

New FAM Cart Configuration
Assume 100 GPM/3-Point FARP

	Hot Refuel Aircraft/min	Talon II Fuel Burn Rate (GPM)	Fuel Price FY00	Fuel Price FY01	FY00 Talon II Fuel Costs	FY01 Talon II Fuel Costs
Pavelow	13.33351897	215.5917247	0.6221	1.014	134.12	218.61
Pavehawk	3.454277122	55.85273953	0.6221	1.014	34.75	56.63

Aircraft	FY00 Tanker Fuel Cost Savings/Per Aircraft Using New FAM Cart	FY01 Tanker Fuel Cost Savings/Per Aircraft Using New FAM Cart
Pavelow	435.30	709.53
Pavehawk	103.62	168.90

Total Fuel Cost Savings (Includes Tanker & Receivers)

Aircraft	FY00 Total Fuel Costs Utilizing Current FAM Cart	FY01 Total Fuel Costs Utilizing Current FAM Cart	FY00 Total Fuel Costs Utilizing New FAM Cart	FY01 Total Fuel Costs Utilizing New FAM Cart	FY00 Fuel Cost Savings/Per Aircraft Using New FAM Cart	FY01 Fuel Cost Savings/Per Aircraft Using New FAM Cart
Pavelow	1520.27	2477.98	963.60	1570.63	556.67	907.35
Pavehawk	369.41	602.13	249.64	406.90	119.78	195.23